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EFFECT OF SULPHUR ON DIFFERENT CROPS AND SOILS[1]

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INTRODUCTION

There has recently been some discussion as to the importance and supply for plant growth of sulphur in its various compounds in soils, and whether or not it may be a limiting element in crop production. While it is one of the essential elements, the amounts found by the old method of ashing plants were so low in most cases that it was generally assumed there was an abundant supply of its compounds in soils for all crop requirements. More recently, however, it has been demonstrated by improved methods of analysis that most plants contain much more sulphur than was formerly thought to be the case, owing to the fact that in many instances by the old method the bulk of the sulphur was lost on ashing the plant, and therefore was overlooked. The question then arose as to whether there is an ample supply of sulphur compounds in soils for crop needs and especially for the best growth of those which are now known to have a high sulphur content.

Hart and Peterson (4),[3] of Wisconsin, later the writer (5), and afterwards Brown and Kellogg (2), of Iowa, Ames and Boltz (1), of Ohio, and others have found that the sulphur content of many soils is low and that there has been a decided loss of sulphur in some soils which have been cultivated for a long term of years when compared with the corresponding virgin soils.

Some investigators contend that, although some soils are low in sulphur, lower in many cases than in phosphorus, this is compensated for by the amount brought down in the rainfall; and as a result it will never be a limiting element in crop production. There are others, however,

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[2] The writer desires to express his thanks to Dr. Peter, for his helpful suggestions in the preparation of the manuscript, and to the county agents who assisted in the collection of the soils.

[3] Reference is made by number to "Literature cited," p. 103.

who maintain that the sulphur brought down in the rainfall will not equal the loss of this element in the drainage, and their point seems to be established by the limited work that has been done along this line. They contend that the application of sulphur compounds may be beneficial for the maximum production of crops high in sulphur when they are grown on soils that are low in this element.

To establish this point, numerous experiments have been carried on, at first abroad and later in this country; and many of these have been mentioned in former publications (1–6). Since then other work has been published or started along this line, but it is not thought necessary to describe these experiments here further than to state that in some cases decidedly beneficial results have been obtained by applying sulphur or its compounds to some soils and crops; in other instances no benefits were obtained; and in still other experiments an injury was noted. These variations are to be expected when different soils and crops are employed in experiments.

In demonstrating the effect of a given element on plant growth it is sometimes extremely difficult to arrange the experiment so as to prove the desired point, for the reason that the element is generally applied in combination with other elements; consequently the results are not always easy of interpretation.

EXPERIMENTAL WORK

In an effort to avoid the above difficulty the writer used flowers of sulphur mixed with soil to which the necessary fertilizing ingredients were added, together with calcium carbonate. For this purpose eight surface soils, taken to a depth of 6⅔ inches, each representing a distinct type in Kentucky, were selected; and on these were grown five different crops. These soils had been in cultivation for a number of years and, with one or two exceptions, had had little manure or fertilizer added. Their locations and descriptions are as follows:

No. 892.—Eastern coal-field area, Lawrence County, from the farm of Ernest Shannon, 3 miles west of Louisa and 20 rods north of the Louisa-Bussyville road. This land had been cultivated over 60 years; no fertilizer used; produced about 20 bushels of corn per acre. The land appeared to be somewhat worn.

No. 893.—St. Louis-Chester area, Warren County, from the Alderson farm, 1 mile west of Bowling Green. This land had been cultivated for 60 years; no fertilizer used; produced about 20 bushels of corn and 15 bushels of wheat per acre.

No. 894.—Cincinnatian area, Mason County, from the farm of John M. Chambers, about 2½ miles northwest of Washington. This land had been continuously cropped for nearly 100 years; very little fertilizer added; was worn out and produced very poor crops.

No. 895.—Western coal-field area, Muhlenburg County, from the Station experiment field, 2½ miles southwest of Greenville. This land had been cultivated for 40 years, and some fertilizer and manure used. It produced 30 bushels of corn, 12 bushels of wheat, and 1 ton of hay per acre.

No. 896.—Keokuk-Waverly area, Barren County, from the Underwood farm near Roseville. The land had been long in cultivation; was worn out; had little fertilizer used and produced 20 bushels corn, 8 bushels wheat, and 12 bushels oats per acre.

No. 897.—Quaternary area, McCracken County, from the Station experiment field, about 3 miles southwest of Paducah, at Lone Oak. A part of this land had been cultivated for 15 years, the remainder for 30 years. Some stable manure had been added. It produced about 15 bushels of corn, 8 bushels of wheat, and 1 ton of hay per acre.

No. 898.—Devonian area, Madison County, from the farm of Mark Settle, northwest of Big Hill. This land had been cultivated for 50 years; was much worn; no fertilizers used. It produced 15 bushels of corn, 10 bushels of wheat, and ½ ton of hay per acre.

No. 899.—Silurian area, Jefferson County, from a farm adjoining the Fair Grounds woods at Fern Creek. The land had been cultivated for many years; was much worn; no commercial fertilizers and little stable manure used. It produced light crops.

Before the experiments were started the soils were partially analyzed and found to have the following composition, in pounds per acre, on assuming that the surface 6⅔ inches weighs 2,000,000 pounds (Table I):

TABLE I.—*Composition of experimental Kentucky soils*

Soil number.	Total phosphorus.[a]	Total sulphur.[b]	Sulphate sulphur.[c]	Calcium carbonate requirement.[d]
892	360	180	160	393
893	540	400	140	129
894	1,540	520	180	3,176
895	520	420	200	107
896	400	700	240	143
897	520	400	200	36
898	400	240	200	1,335
899	600	380	200	107

[a] Magnesium-nitrate method (Wiley, H. W., ed. Official and provisional methods of analysis, Association of Official Agricultural Chemists. As compiled by the Committee on Revision of Methods. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 2. 1908.)
[b] Sodium-peroxid method (5).
[c] Hydrochloric-acid (sp. gr. 1.115) digestion (Wiley, H. W. Idem, p. 14).
[d] Hopkins method (Wiley, H. W. Idem, p. 20).

These soils were air-dried, put through a coarse sieve, and 15 pounds (in triplicate) were placed in 2-gallon glazed earthenware jars, supplied with drainage and thoroughly mixed with the following materials, added at the rate of pounds per acre of soil on the above assumption of soil weight:

500 pounds of tricalcium phosphate, C. P., precipitated.
200 pounds of potassimum nitrate, C. P.
8,000 pounds of calcium carbonate, C. P.
100 pounds of flowers of sulphur; or
200 pounds of flowers of sulphur.

Triplicate jars like the above were also prepared of each soil, except that the sulphur was omitted; and these were used as controls.

SERIES I: SOYBEANS.—Fifteen uninoculated soybean seeds (*Soja max*) were planted in each jar in the greenhouse on November 2, 1914, and

watered in all cases with the same amount of distilled water. When the plants were about 3 inches in height, they were thinned to 6 plants of average size in each jar. After the pods had matured, which took place at different times, according to the soil, the plants were cut close to the ground, air-dried, and weighed. They were cut on the following dates: No. 894 and 895 on December 31; No. 892 and 893 on January 9; and the remainder on January 19, 1915.

SERIES II: CLOVER.—After the plants in Series I had been cut, the soil in each jar was sifted, and 25 inoculated red-clover seeds (*Trifolium pratense*) planted. After germinating, these were thinned to 15 average-sized plants in each jar. The plants were allowed to grow until they had attained a height of about 10 inches. Four cuttings were made at a distance of about 2 inches from the crown. When cut in this manner and not allowed to blossom, the plants grew faster, and this procedure was followed until July 14, when the weather became too warm for greenhouse experiments.

SERIES III: OATS.—The soil in each jar of Series II was pulverized and stirred to a depth of 6 inches, and on December 23, 1915, 36 Burt oat seeds (*Avena sativa*) were planted in each. Two weeks later they were thinned to 25 average-sized plants in each jar, and potassium nitrate was then added in solution at the rate of 100 pounds per acre and repeated on February 15. On May 12, 1916, after the seed had matured, the plants were cut close to the ground, air-dried, and weighed.

SERIES IV: ALFALFA.—Similar jars of the same soils used in Series I to III were prepared, and, in addition, jars representing 200 pounds of sulphur per acre were included in triplicate. Thirty-five inoculated alfalfa seeds (*Medicago sativa*) were planted on October 14, 1914, in each of the jars containing soil from Warren, Mason, Muhlenburg, and McCracken Counties, and a like number on November 6 in the remainder. On November 17 the plants were thinned to 15 average-sized plants, and cuttings were made at intervals—whenever the plants attained a height of about 10 inches—just as was done in Series II. Five cuttings were made from the Lawrence, Barren, Madison, and Jefferson County soils, and six from the remainder. Final cuttings on all were made on July 9, 1915, when the experiments were stopped.

SERIES V: WHEAT.—The soils in Series IV were stirred and pulverized to a depth of 6 inches and on December 23, 1915, were planted with 36 Jersey Fultz wheat seeds (*Triticum aestivum*) in each jar. The plants were thinned to 25 average-sized plants, and potassium nitrate was added in the same amounts and at the same time as in Series III. On June 13, 1916, after the seeds had matured, the plants were cut close to the ground, air-dried, and weighed.

The weight in grams of the total air-dry materials in Series I–V, together with the percentage gains or losses are given in Table II.

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*

LAWRENCE COUNTY SOIL, EASTERN COAL-FIELD AREA

Quantity of sulphur per acre.	Soybeans.		Clover.	Oats.		Alfalfa.	Wheat.	
	Hay.	Grain.	Hay.	Straw.	Grain.	Hay.	Straw.	Grain.
Control	6.9	0.5	24.1	28.7	11.3	23.1	26.6	1.5
Do	4.7	1.3	15.4	30.8	12.3	22.6	23.4	1.6
Do	4.9	1.1	17.3	25.3	12.7	21.0	24.2	1.9
Total	16.5	2.9	56.8	84.8	36.3	66.7	74.2	5.0
100 pounds	6.0	.9	25.4	29.6	13.4	22.5	29.9	3.2
Do	6.4	1.1	18.6	28.8	13.2	17.3	25.4	1.6
Do	5.2	1.0	23.6	30.3	12.7	21.5	25.1	1.9
Total	17.6	3.0	67.6	88.7	39.3	61.3	80.4	6.7
200 pounds						21.0	28.6	2.4
Do						23.6	24.3	1.7
Do						22.7	32.0	2.0
Total						67.3	84.9	6.1

WARREN COUNTY SOIL, ST. LOUIS-CHESTER AREA

Control	8.7	.8	33.0	20.9	9.1	34.1	23.6	4.4
Do	7.6	.8	27.8	26.1	8.9	40.2	24.7	5.3
Do	7.2	1.6	26.0	22.5	9.6	38.9	21.9	3.1
Total	23.5	3.2	86.8	69.5	27.6	113.2	70.2	12.8
100 pounds	5.2	1.0	27.2	25.5	9.5	39.8	22.2	2.9
Do	6.5	1.2	24.1	28.9	9.1	41.1	28.0	4.0
Do	7.3	1.1	28.1	22.6	8.4	39.1	25.0	5.0
Total	19.0	3.3	79.4	77.0	27.0	120.0	75.2	11.9
200 pounds						40.3	32.8	6.2
Do						41.2	26.5	5.5
Do						41.4	26.4	4.6
Total						122.9	85.7	16.3

MASON COUNTY SOIL, CINCINNATIAN AREA

Control	9.5	4.6	27.7	17.5	6.5	36.1	24.0	5.0
Do	8.5	4.4	19.0	17.3	7.7	39.0	26.5	3.5
Do	8.2	4.1	19.5	23.3	8.7	37.9	27.0	4.0
Total	26.2	13.1	66.2	58.1	22.9	113.0	77.5	12.5
100 pounds	9.1	4.8	15.4	18.6	8.4	43.0	26.0	4.0
Do	8.2	4.1	13.9	19.8	8.2	47.1	29.0	5.0
Do	9.2	4.9	17.2	23.8	7.2	40.2	25.3	4.7
Total	26.5	13.8	46.5	62.2	23.8	130.3	80.3	13.7
200 pounds						36.2	31.4	5.6

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*—Continued

MUHLENBURG COUNTY SOIL, WESTERN COAL-FIELD AREA

Quantity of sulphur per acre.	Soybeans.		Clover.	Oats.		Alfalfa.	Wheat.	
	Hay.	Grain.	Hay.	Straw.	Grain.	Hay.	Straw.	Grain.
Control	11.8	7.7	27.2	23.7	10.3	38.3	30.0	7.0
Do	11.6	6.3	29.0	21.7	9.3	39.2	30.2	6.8
Do	12.2	6.8	26.0	25.9	9.2	40.1	27.0	5.0
Total	35.6	20.8	82.2	71.3	28.8	117.6	87.2	18.8
100 pounds	11.0	6.8	24.6	25.3	10.7	42.5	31.3	5.7
Do	9.4	3.8	22.5	24.3	9.7	41.1	25 6	6.4
Do	12.5	5.6	20.5	24.7	8.3	39.7	29.7	7.3
Total	32.9	16.2	67.6	74.3	28.7	123.3	86.6	19.4
200 pounds						29.9	26.0	5.0
Do						44.1	27.3	2.7
Do						39.2	26.9	5.1
Total						113.2	80.2	12.8

BARREN COUNTY SOIL, KEOKUK-WAVERLY AREA

Control	8.0	1.0	28.7	31.2	12.9	27.8	31.6	5.4
Do	5.4	2.4	28.1	27.4	14.6	26.4	31.5	6.5
Do	7.1	2.3	17.9	29.5	13.5	28.0	33.2	5.8
Total	20.5	5.7	74.7	88.1	41.0	82.2	96.3	17.7
100 pounds	7.4	2.4	28.9	28.6	12.4	24.0	30.8	6.2
Do	5.0	1.8	20.5	25.8	12.3	30.9	33.7	6.3
Do	6.4	3.3	22.6	31.3	12.7	28.4	33.9	6.1
Total	18.8	7.5	72.0	85.7	37.4	83.3	98.4	18.6
200 pounds						25.1	32.5	6.5
Do						25.6	28.7	3.3
Do						27.4	34.2	6.8
Total						78.1	95.4	16.6

MCCRACKEN COUNTY SOIL, QUATERNARY AREA

Control	9.9	2.5	28.4	21.9	12.1	45.8	29.5	6.5
Do	9.1	2.7	32.3	32.9	14.1	46.5	32.1	6.9
Do	8.6	3.0	14.8	29.1	13.9	49.3	32.7	6.3
Total	27.6	8.2	75.5	83.9	40.1	141.6	94.3	19.7
100 pounds	9.5	2.4	18.8	32.1	15.9	48.4	30.6	5.4
Do	8.6	2.4	22.7	32.9	14.1	50.8	29.1	5.9
Do	10.2	2.2	23.6	28.3	12.7	51.4	28.9	7.1
Total	28.3	7.0	65.1	93.3	42.7	150.6	88.6	18.4
200 pounds						46.9	30.7	8.3
Do						49.8	32.9	7.1
Do						53.2	31.6	6.4
Total						149.9	95.2	21.8

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*—Continued

MADISON COUNTY SOIL, DEVONIAN AREA

Quantity of sulphur per acre.	Soybeans.		Clover.	Oats.		Alfalfa.	Wheat.	
	Hay.	Grain.	Hay.	Straw.	Grain.	Hay.	Straw.	Grain.
Control	7.0	2.3	27.2	23.0	13.0	19.9	33.4	8.6
Do	6.8	2.2	27.1	26.8	12.2	30.2	23.0	3.1
Do	6.7	2.4	24.8	22.3	12.7	16.9	33.3	5.7
Total	20.5	6.9	79.1	72.1	37.9	67.0	89.7	17.4
100 pounds	9.2	2.6	24.1	23.5	12.5	18.8	26.8	3.3
Do	7.6	1.7	30.0	25.4	13.6	30.7	25.1	4.9
Do	8.6	3.1	24.0	23.1	15.0	28.7	26.4	5.6
Total	25.4	7.4	78.1	72.0	41.1	78.2	78.3	13.8
200 pounds	.....	.....	.....	.....	.....	27.4	30.7	7.3
Do	.....	.....	.....	.....	.....	28.3	19.5	2.5
Do	.....	.....	.....	.....	.....	30.5	32.3	6.7
Total	.....	.....	.....	.....	.....	86.2	82.5	16.5

JEFFERSON COUNTY SOIL, SILURIAN AREA

Control	10.4	2.6	13.6	24.5	11.5	35.7	33.4	8.6
Do	8.8	2.8	21.3	26.7	13.3	34.9	33.8	8.2
Do	9.4	3.1	13.6	25.9	13.1	38.2	34.5	7.5
Total	28.6	8.5	48.5	77.1	37.9	108.8	101.7	24.3
100 pounds	10.9	3.2	16.1	24.9	13.1	37.1	34.3	8.7
Do	11.8	3.4	19.0	22.7	13.3	41.0	32.6	8.4
Do	10.5	3.5	15.7	24.0	13.0	38.9	33.4	7.6
Total	33.2	10.1	50.8	71.6	39.4	117.0	100.3	24.7
200 pounds	.....	.....	.....	.....	.....	34.8	32.0	7.0
Do	.....	.....	.....	.....	.....	33.8	31.4	8.6
Do	.....	.....	.....	.....	.....	35.1	31.7	8.3
Total	.....	.....	.....	.....	.....	103.7	95.1	23.9

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*—Continued.

PERCENTAGE GAIN OR LOSS

County.	Quantity of sulphur added per acre.	Soybeans.		Clover hay.	Oats.		Alfalfa hay.	Wheat.	
		Hay.	Grain.		Straw.	Grain.		Straw.	Grain.
	Pounds.								
Lawrence	100	+ 6.9	+ 3.4	+19.0	+ 4.6	+8.3	− 8.1	+ 8.4	+34.0
Do	200	.....	.....	.....	.....	.....	+ .9	+14.4	+22.0
Warren	100	−19.1	+ 3.1	− 8.5	+10.8	−2.2	+ 6.0	+ 7.1	− 7.0
Do	200	.....	.....	.....	.....	.....	+ 8.6	+22.1	+27.3
Mason	100	+ 1.1	+ 5.3	−29.8	+ 7.1	+3.9	+15.3	+ 3.6	+ 9.6
Do	200	.....	.....	.....	.....	.....	− 4.0	+21.7	+33.3
Muhlenburg	100	− 7.6	−22.1	−17.3	+ 4.2	− .03	+ 4.8	− .7	+ 3.2
Do	200	.....	.....	.....	.....	.....	− 3.7	− 8.0	−31.9
Barren	100	− 8.3	+31.6	− 3.6	− 2.7	−8.8	+ 1.3	+ 2.2	+ 5.1
Do	200	.....	.....	.....	.....	.....	− 5.0	− .9	− 6.2
McCracken	100	+ 2.5	−14.6	−13.7	+11.2	+6.5	+ 6.4	− 6.0	− 6.6
Do	200	.....	.....	.....	.....	.....	+ 5.9	+ .9	+10.7
Madison	100	+23.9	+ 7.2	− 1.3	− .1	+8.4	+16.7	−12.7	−20.7
Do	200	.....	.....	.....	.....	.....	+28.7	− 8.0	− 5.2
Jefferson	100	+16.1	+18.8	+ 4.7	− 7.1	+4.0	+ 7.5	− 1.4	+ 1.6
Do	200	.....	.....	.....	.....	.....	− 4.7	− 6.5	− 1.6

EFFECT OF SULPHUR ON THE TOTAL AND SULPHATE-SULPHUR CONTENT OF SOYBEANS, CLOVER, AND ALFALFA

The air-dried plants in Series I, II, and IV, were finely ground for this work, a composite sample being made of the triplicates in each case, and the soybean seeds were ground with the corresponding sample of hay.

The total sulphur determinations were made by the sodium-peroxid method [1] and the sulphate sulphur was determined by the following procedure:

Ten gm. of material were digested in 400 c. c. of water on the water bath for several hours, with frequent stirring. It stood overnight, and was made to 500 c. c. volume, first deducting the volume occupied by the sample. This was then filtered, and a 5-gm. aliquot used, to which was added 1 c. c. of hydrochloric acid (1:1) to precipitate the protein and organic matter. The whole was then heated on the water bath several hours longer, allowed to stand overnight, filtered, and washed. The filtrate was made slightly acid with hydrochloric acid, heated, and barium sulphate precipitated by adding, hot, 10 per cent barium-chlorid solution, and letting it stand overnight.

The results obtained on the above samples are given in Table III.

[1] A slight modification was used, which is now the official method of the Association of Official Agricultural Chemists (Wiley, H. W., ed. Op. cit., p. 23.)

TABLE III.—*Percentage of total and sulphate sulphur in air-dry soybeans, clover, and alfalfa*

SOYBEANS

Quantity of sulphur to the acre.	Lawrence County.	Warren County.	Mason County.	Muhlenburg County.	Barren County.	McCracken County.	Madison County.	Jefferson County.
Control:								
Total sulphur	0.207	0.301	0.252	0.260	0.209	0.223	0.198	0.202
Sulphate sulphur	.025	.038	.079	.068	.039	.049	.042	.056
Residual sulphur	.182	.263	.173	.192	.170	.174	.156	.146
100 pounds:								
Total sulphur	.302	.376	.298	.278	.229	.247	.237	.254
Sulphate sulphur	.037	.044	.096	.086	.035	.054	.056	.083
Residual sulphur	.265	.332	.202	.192	.194	.193	.181	.171

CLOVER

Control:								
Total sulphur	0.238	0.276	0.275	0.304	0.219	0.213	0.279	0.231
Sulphate sulphur	.097	.140	.125	.143	.084	.081	.148	.071
Residual sulphur	.141	.136	.150	.161	.135	.132	.131	.160
100 pounds:								
Total sulphur	.267	.281	.321	.379	.248	.291	.340	.351
Sulphate sulphur	.130	.152	.178	.218	.100	.107	.198	.195
Residual sulphur	.137	.129	.143	.161	.148	.184	.142	.156

ALFALFA

Control:								
Total sulphur	0.410	0.457	0.352	0.409	0.334	0.306	0.387	0.284
Sulphate sulphur	.168	.223	.142	.209	.152	.123	.204	.093
Residual sulphur	.242	.234	.210	.200	.182	.183	.183	.191
100 pounds:								
Total sulphur	.511	.480	.425	.451	.397	.398	.467	.435
Sulphate sulphur	.265	.256	.205	.265	.206	.166	.267	.248
Residual sulphur	.246	.224	.220	.186	.191	.232	.200	.187
200 pounds:								
Total sulphur	.517	.503	.528	.462	.422	.409	.474	.412
Sulphate sulphur	.286	.301	.349	.295	.213	.212	.298	.218
Residual sulphur	.231	.202	.179	.167	.209	.197	.176	.194

FORMATION OF SULPHATE IN SEEDS ON GERMINATION

As the results in Table III indicate that the excess of sulphur in those plants which have been grown in soil to which this element has been added exists in the form of sulphate, it was thought that it might be of interest to ascertain whether sulphate is formed in seeds from their sulphur compounds when they are allowed to germinate.

As a control the sulphate was determined in the finely ground ungerminated seed by the same method used for the work in Table III, and about the same weight of the seeds were then allowed to germinate in covered dishes between cheesecloth kept moistened with distilled water, after which the sample was ground in a mortar and the sulphate determined. As a precaution all precipitates of barium sulphate were fused with sodium carbonate and reprecipitated and blanks made on the reagents.

The results of these experiments are given in Table IV.

TABLE IV.—*Percentage of sulphur existing as sulphate in seeds before and after germination*

Variety.	Before germination.	After germination.	Increase during germination.	Period of germination.
				Days.
Corn	None.	None.	None.	6
Beans	None.	0.0003	0.0003	6
Cowpeas	None.	.0079	.0079	6
Alfalfa	None.	.0144	.0144	6
Millet	None.	.0223	.0223	6
Oats	None.	.0312	.0312	6
Soybeans	0.0007	.0034	.0027	6
Wheat	.0007	.0219	.0212	6
Hemp	.0014	.0107	.0093	6
Timothy	.0034	.0316	.0282	6
Rye	.0048	.0168	.0120	6
Tobacco	.0072	.0261	.0189	13
Peas	.0117	.0212	.0095	6
Onion	.0220	.0566	.0346	6
Bluegrass	.0258	.0309	.0051	13
Clover	.0483	.0447	[a] .0006	6

[a] Loss.

GENERAL DISCUSSION

While a few of the duplicates in Table II vary widely, yet on the whole they agree fairly well, considering work of this character. If an allowance of 10 per cent, compared with the controls, which is a safe amount, is made for unavoidable factors, then we find from an examination of Table II that applications of sulphur have affected the crops grown on the soils from the different counties as follows:

LAWRENCE.—Beneficial, clover from the smaller application and wheat grain and straw from the larger application. Injurious, none.

WARREN.—Beneficial, oat straw from the smaller application, and wheat, both in grain and straw, from the larger application. Injurious, soybean hay.

MASON.—Beneficial, alfalfa and wheat, both in grain and straw, from the larger application. Injurious, clover.

MUHLENBURG.—Beneficial, none. Injurious, soybean grain, clover, and wheat grain from larger application.

BARREN.—Beneficial, soybean grain. Injurious, none.

MCCRACKEN.—Beneficial, oat straw and wheat grain from larger application. Injurious, soybean grain and clover.

MADISON.—Beneficial, soybean hay and alfalfa. Injurious, wheat, both in grain and straw, from smaller application.

JEFFERSON.—Beneficial, soybeans, both in hay and grain. Injurious, none.

From the foregoing we find that the sulphur has affected the crops differently, depending on the soil. Some undoubtedly were benefited, others were injured, while in many cases no effect was apparent. On the whole, there is a preponderance of gains from the sulphur, although generally small.

Some observers have found that sulphur had a more marked effect on certain crops when applied to soils fairly well supplied with organic matter. What the effect would have been if such had been the case here or if the other fertilizing ingredients had been omitted is not easy to forecast, for, as stated before, it is difficult to have all soil conditions ideal in order to prove a certain point. Soil fertility involves so many factors that its study is very complicated. The question of mineral plant food has occupied considerable attention, and rightly so, but oftentimes another important side has been overlooked—namely, the organic matter, involving, as it does, all bacterial activities of the soil. If a bacterial study was carried on in mineral-nutrition work, probably different deductions would be drawn then where each is considered alone. In this connection it might be of interest to state that Fred and Hart (3) have been found that soluble phosphates have a more marked effect on promoting the bacterial activity of a soil than sulphates; and for this reason, while sulphates are important and as low in amount in most soils as phosphates, they will not in all probability have the same crop-producing power as the phosphates.

From an examination of Tables III, it will be found that applications of sulphur increased the total and sulphate-sulphur content of the plant; and the larger the application, the greater the increase. Furthermore, it will also be observed that in the clover and alfalfa, the sulphur marked "residual" more nearly approaches a constant figure, regardless of whether sulphur was applied or not. This does not hold true with respect to the soybeans in most cases, however, and this indicates that the excess sulphur in the clover and alfalfa plants exists as

sulphate, while part of the excess in the soybeans is in a form other than sulphate.

As sulphur is combined with the protein of plants, it was thought that in the soybeans protein determinations might show that where an increased sulphur content is shown, owing to the sulphur applied, a correspondingly larger protein content might be found; but such is not always the case, as will be seen in Table V. For these determinations the same materials used for the sulphur work in Table III were employed.

TABLE V.—*Protein in air-dry soybeans, tops and seed*

County.	Protein.			
	Controls.		Sulphur, 100 pounds per acre.	
	Per cent.	Weight (in grams).	Per cent.	Weight (in grams).
Lawrence	24.3	4.7	24.5	5.0
Warren	25.5	6.8	24.9	5.6
Mason	23.6	9.3	21.0	8.5
Muhlenburg	23.2	13.1	21.5	10.6
Barren	26.5	6.9	26.9	7.1
McCracken	25.1	9.0	26.5	9.4
Madison	29.8	8.2	28.5	9.3
Jefferson	25.7	9.5	23.6	10.2

The results in Table IV are interesting in showing that some seeds contain no sulphate soluble in water; others contain small amounts; while some are fairly well supplied. Furthermore, these results show that in most cases more or less sulphate is formed from the reserve sulphur compounds in the seed on germinating, but there are exceptions—namely, corn and clover—and the latter is of particular interest, since it possessed the highest sulphate content and seemed to show a slight loss on germination.

SUMMARY

(1) Soybeans, clover, oats, alfalfa, and wheat were grown in the greenhouse on eight soils, each taken from a different county and representing a distinct type in Kentucky. They were more or less impoverished by cultivation. To these soils applications of flowers of sulphur at the rate of 100 and 200 pounds per acre, together with the calcium carbonate and other fertilizing ingredients, were added.

(2) The results show that the sulphur increased the production of some crops, had no effect on others, and on some was injurious, depending on the crop and the soil on which it was grown. There was a preponderance of gains, however, from the sulphur application, but these were generally small.

(3) Analyses of some of the crops show that the sulphur increased the total and sulphate-sulphur content of the plant, and the greater the application, the greater the increase.

(4) Where sulphur wasa pplied to clover and alfalfa, the excess sulphur in those plants was in the form of sulphate, while in soybeans part of the excess was in another form.

(5) In the soybeans which showed an increased sulphur content, no corresponding increased protein content was always found. In five instances out of eight, however, soybeans grown in soil where sulphur was added show an increase in the total weight of protein.

(6) It was found that, of the 16 varieties of field and garden seeds examined, some contain sulphates, while others do not, but that, on germinating, all except two form a greater or less amount of sulphate. The highest sulphate content obtained in the ungerminated seed was 0.048 per cent, in clover, and the increase due to germination varied from none, in corn, to 0.035 per cent, in the onion. There was a slight loss in only one sample, clover.

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A STATISTICAL STUDY OF SOME INDIRECT EFFECTS OF CERTAIN SELECTIONS IN BREEDING INDIAN CORN

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INTRODUCTION

At the Illinois Agricultural Experiment Station a considerable number of experiments are being conducted in the breeding of Indian corn (*Zea mays*) by the selection of parents with respect to particular characters. One of the best known of these experiments is concerned with selections with regard to chemical composition. This corn now consists of four strains, known as the "high-protein," the "low-protein," the "high-oil," and the "low-oil" strains. Other selection experiments are concerned with such characters as the height of ears on stalks, the number of ears per stalk, and the inclination of the ear on the stalk.

The primary purpose of these experiments is to determine what progress, if any, can be made in regard to particular characters by selecting for parents from year to year with respect to such characters. It is the purpose of the present paper to report the results of an investigation into what may be called the indirect effects of some of the above-mentioned selections, by a statistical investigation of the changes that have taken place in certain physical characters of the ears of corn. The physical characters treated are length, circumference, weight of ears, and the number of rows of kernels on the ears. A part of this work on physical characters of ears has been in progress on each of 11 generations of corn. Each year we have either measured for each strain all the measureable ears produced, or a random sample of sufficient size to insure fairly small probable errors. To give a notion of the extent of the data used and of the statistical analysis, it may be stated that this analysis involves the preparation of 476 distinct frequency distributions. It would hardly be feasible to exhibit each of these frequency distributions, but we shall present in Table I, as a representative illustration, the 16 distributions of the four chemical composition strains for the crop of 1914.

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TABLE I.—*Frequency distributions with respect to physical characters of the ears of four strains of corn bred for chemical composition—crop of 1914*

HIGH-PROTEIN STRAIN

Length of ears.		Weight of ears.		Circumference of ears.		Rows of kernels.	
Inches.	Frequency.	Ounces.	Frequency.	Inches.	Frequency.	Number.	Frequency.
3.0	1	2	4	4.00	1	8	1
3.5	6	3	19	4.25	9	10	25
4.0	8	4	43	4.50	26	12	236
4.5	13	5	66	4.75	71	14	241
5.0	28	6	135	5.00	113	16	74
5.5	36	7	144	5.25	158	18	13
6.0	42	8	96	5.50	142	.....	.....
6.5	67	9	28	5.75	73	.....	.....
7.0	95	10	6	6.00	27	.....	.....
7.5	118	.....	.....	6.25	5	.....	.....
8.0	100	.....	.....	6.50	8	.....	.....
8.5	89	.....	.....	6.75	5	.....	.....
9.0	43	.....	.....	7.00	0	.....	.....
9.5	17	.....	.....	7.25	1	.....	.....
10.0	3	.....	.....	.....	.....	.....	.....

LOW-PROTEIN STRAIN

3.0	.....	2	4	4.00	.....	8	.....
3.5	3	3	10	4.25	.....	10	9
4.0	4	4	17	4.50	1	12	117
4.5	6	5	21	4.75	6	14	179
5.0	11	6	38	5.00	27	16	124
5.5	17	7	59	5.25	36	18	41
6.0	12	8	78	5.50	58	20	7
6.5	34	9	97	5.75	99	22	1
7.0	34	10	72	6.00	113	.....	.....
7.5	66	11	49	6.25	98	.....	.....
8.0	62	12	15	6.50	54	.....	.....
8.5	93	13	4	6.75	15	.....	.....
9.0	83	14	1	7.00	9	.....	.....
9.5	54	.....	.....	7.25	2	.....	.....
10.0	34	.....	.....	.....	.....	.....	.....
10.5	1	.....	.....	.....	.....	.....	.....
11.0	2	.....	.....	.....	.....	.....	.....

HIGH-OIL STRAIN

2.5	2	2	16	4.00	2	8	.....
3.0	4	3	44	4.25	15	10	2
3.5	7	4	88	4.50	31	12	78
4.0	17	5	145	4.75	57	14	158
4.5	23	6	114	5.00	103	16	171
5.0	48	7	61	5.25	96	18	49
5.5	71	8	23	5.50	117	20	3
6.0	59	9	6	5.75	84	22	3
6.5	116	.....	.....	6.00	34	.....	.....
7.0	85	.....	.....	6.25	11	.....	.....
7.5	77	.....	.....	6.50	4	.....	.....
8.0	34	.....	.....	.....	.....	.....	.....
8.5	27	.....	.....	.....	.....	.....	.....
9.0	10	.....	.....	.....	.....	.....	.....
9.5	2	.....	.....	.....	.....	.....	.....
10.0	1	.....	.....	.....	.....	.....	.....

TABLE I.—*Frequency distributions with respect to physical characters of the ears of four strains of corn bred for chemical composition—crop of 1914*—Continued

LOW-OIL STRAIN

Length of ears.		Weight of ears.		Circumference of ears.		Rows of kernels.	
Inches.	Frequency.	Ounces.	Frequency.	Inches.	Frequency.	Number.	Frequency.
2.5	.....	2	.....	4.00	1	8	2
3.0	3	3	4	4.25	0	10	59
3.5	2	4	19	4.50	3	12	287
4.0	10	5	40	4.75	7	14	185
4.5	22	6	83	5.00	19	16	30
5.0	25	7	126	5.25	20	18	4
5.5	29	8	97	5.50	46	.....	.....
6.0	62	9	100	5.75	77	.....	.....
6.5	106	10	55	6.00	110	.....	.....
7.0	100	11	23	6.25	117	.....	.....
7.5	116	12	9	6.50	130	.....	.....
8.0	95	13	4	6.75	57	.....	.....
8.5	60	.....	.....	7.00	36	.....	.....
9.0	18	.....	.....	7.25	13	.....	.....
9.5	7	.....	.....	7.50	3	.....	.....
10.0	2	.....	.....	7.75	1	.....	.....

The character of the frequency distributions may be described in a general way as not far from a symmetrical form. Occasionally a distribution has presented an appearance that seemed pretty decidedly skew, and we have followed such cases into succeeding generations without good evidence that such decided skew form persisted in later generations. On this account it seems likely that the decided skew condition was due mainly to soil differences on a given plot. There is, however, some tendency for the distributions as to length and weight of ears to be slightly skew, with the mode greater than the mean.

We have tested a number of the distributions, and found some of the normal type, and some differing significantly from the normal type. Taken as a whole, it seems, however, that these distributions are sufficiently near the normal type, to be well described for our purposes by the means, standard deviations, and coefficients of variability.

THE FOUR STRAINS WITH RESPECT TO CHEMICAL COMPOSITION

These four strains were produced from the same original stock (163 ears) and each seed selection was made from the highest (or lowest) ears within the strain with respect to the character in question. For example, the high-protein strain is the offspring of those ears showing the highest protein content in the original stock, and was developed by the selection, for successive generations of planting, of the highest protein ears, always within the high-protein strain. In a similar manner, each of the other three strains was produced. Attention [1] has been called to some indi-

[1] DAVENPORT, Eugene. PRINCIPLES OF BREEDING, p. 447. Boston, 1907.

rect effects of selection as shown in the crop of 1905, after selection for chemical composition had been made since 1897. It was there shown that the four strains exhibit some significant differences with respect to physical characters of ears. As we have measured each ear of a fair-sized random sample of ears from each strain for crops grown from 1905–1915, we are now in a position to determine whether the differences existing in 1905 have persisted pretty regularly under changed conditions of soil and season, or if some further indirect influence of the selection for chemical composition is to be noted in considering the four physical characters on which we have collected data. Table II gives the means, empirical modes, standard deviations, and coefficients of variability of the length of ears, the circumference of ears, the weight of ears, and the number of rows of kernels on ears, for each of the four strains bred for chemical composition, for the 11 crops from 1905 to 1915, inclusive.

TABLE II.—*Type and variability of the four chemical-composition strains of Indian corn for 11 crops, 1905 to 1915*

CROP OF 1905

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High-protein	7.21±0.04	7.5	1.27±0.03	17.6±0.4
Low-protein	7.80± .04	8.5	1.54± .03	19.7± .4
High-oil	6.87± .04	7.0	1.39± .03	20.2± .4
Low-oil	7.48± .04	8.0	1.30± .03	17.4± .4
Circumference of ear, in inches:				
High-protein	5.71± .01	5.7	.44± .01	7.6± .2
Low-protein	6.51± .02	6.3	.61± .01	9.4± .2
High-oil	6.05± .01	6.3	.53± .01	8.8± .2
Low-oil	6.65± .02	6.9	.59± .01	8.9± .2
Weight of ear, in ounces:				
High-protein	7.53± .04	8.0	2.50± .03	33.2± .4
Low-protein	9.66± .10	10.0	3.30± .07	34.2± .7
High-oil	7.79± .07	9.0	2.43± .05	31.2± .6
Low-oil	9.84± .08	11.0	2.87± .06	29.2± .7
Rows of kernels on ears:				
High-protein	13.72± .03	14.0	1.85± .02	13.5± .2
Low-protein	14.71± .06	14.0	1.94± .04	13.7± .3
High-oil	15.65± .06	16.0	2.08± .04	13.3± .3
Low-oil	12.80± .05	12.0	1.77± .04	13.8± .3

TABLE II.—*Type and variability of the four chemical-composition strains of Indian corn for 11 crops, 1905 to 1915*—Continued

CROP OF 1906

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High-protein	7.880±0.043	8.0	1.201±0.030	15.24±0.39
Low-protein	8.841± .050	10.0	1.364± .035	15.43± .43
High-oil	7.606± .042	7.5	1.014± .030	13.33± .41
Low-oil	8.378± .056	8.5	1.510± .040	18.02± .49
Circumference of ear, in inches:				
High-protein	5.863± .014	6.0	.393± .010	6.70± .17
Low-protein	6.495± .018	6.6	.478± .013	7.38± .19
High-oil	6.134± .017	6.0	.417± .012	6.80± .20
Low-oil	6.717± .018	6.9	.515± .013	7.52± .19
Weight of ear, in ounces:				
High-protein	8.289± .081	8.5	2.061± .057	24.86± .72
Low-protein	10.770± .110	11.0	2.680± .071	24.88± .74
High-oil	8.850± .075	10.0	1.763± .053	19.92± .63
Low-oil	11.498± .130	14.0	3.349± .091	29.13± .84
Rows of kernels on ears:				
High-protein	13.774± .060	14.0	1.707± .042	12.39± .31
Low-protein	14.597± .072	14.0	1.922± .051	13.17± .35
High-oil	14.712± .073	14.0	1.802± .052	12.25± .36
Low-oil	13.310± .067	14.0	1.897± .047	14.25± .38

CROP OF 1907

Length of ear, in inches:				
High-protein	8.474±0.027	9.0	1.392±0.027	16.43±0.33
Low-protein	8.492± .035	9.0	1.249± .025	14.71± .31
High-oil	7.982± .034	8.0	1.242± .024	15.56± .31
Low-oil	8.505± .036	9.0	1.261± .025	14.83± .31
Circumference of ear, in inches:				
High-protein	6.100± .013	6.0	.447± .009	7.33± .14
Low-protein	6.401± .014	6.5	.497± .010	7.76± .16
High-oil	6.428± .013	6.2	.453± .009	7.05± .14
Low-oil	6.800± .015	7.0	.504± .011	7.41± .16
Weight of ear, in ounces:				
High-protein	9.837± .063	10.0	2.095± .045	21.30± .47
Low-protein	10.708± .076	12.0	2.592± .054	24.21± .53
High-oil	10.302± .065	11.0	2.292± .046	22.25± .47
Low-oil	11.702± .075	12.0	2.438± .053	20.83± .44
Rows of kernels on ears:				
High-protein	13.968± .051	14.0	1.799± .036	12.88± .26
Low-protein	14.643± .060	14.0	2.057± .042	14.05± .29
High-oil	15.570± .056	16.0	1.997± .040	12.83± .26
Low-oil	12.523± .048	12.0	1.622± .034	12.94± .28

TABLE II.—*Type and variability of the four chemical-composition strains of Indian corn for 11 crops, 1905 to 1915*—Continued

CROP OF 1908

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High-protein	7.625±0.035	7.5	1.195±0.025	15.67±0.34
Low-protein	8.496± .040	9.0	1.363± .028	16.04± .34
High-oil	7.334± .027	7.5	.983± .019	13.40± .27
Low-oil	8.194± .041	8.0	1.407± .029	17.17± .36
Circumference of ear, in inches:				
High-protein	5.452± .014	5.5	.460± .010	8.44± .18
Low-protein	6.338± .015	6.2	.490± .011	7.76± .17
High-oil	5.774± .012	6.0	.438± .009	7.59± .15
Low-oil	6.336± .016	6.5	.548± .012	8.65± .18
Weight of ear, in ounces:				
High-protein	6.301± .058	6.0	1.804± .041	28.63± .65
Low-protein	9.783± .077	10.0	2.288± .054	23.39± .59
High-oil	7.566± .046	8.0	1.616± .033	21.36± .47
Low-oil	9.944± .089	11.0	2.935± .063	29.52± .68
Rows of kernels on ears:				
High-protein	13.276± .052	14.0	1.631± .037	12.27± .28
Low-protein	13.984± .050	14.0	1.606± .035	11.51± .26
High-oil	15.010± .056	14.0	1.970± .040	13.12± .27
Low-oil	12.326± .050	14.0	1.591± .035	12.90± .30

CROP OF 1909

Length of ear, in inches:				
High-protein	7.680±0.035	7.5	1.127±0.025	14.67±0.35
Low-protein	7.672± .034	8.0	1.221± .024	15.91± .32
High-oil	7.050± .031	7.0	1.140± .022	16.17± .32
Low-oil	7.748± .028	8.0	1.123± .020	14.49± .27
Circumference of ear, in inches:				
High-protein	5.693± .013	5.75	.424± .009	7.45± .17
Low-protein	5.967± .015	5.75	.560± .011	9.38± .19
High-oil	5.914± .013	6.00	.489± .009	8.27± .16
Low-oil	6.660± .013	6.50	.517± .009	7.76± .15
Weight of ear, in ounces:				
High-protein	6.982± .054	7.0	1.694± .039	24.26± .60
Low-protein	7.005± .068	7.0	2.407± .048	34.36±1.08
High-oil	6.837± .052	7.0	1.880± .037	27.50± .82
Low-oil	9.244± .059	9.0	2.275± .042	24.61± .48
Rows of kernels on ears:				
High-protein	13.020± .050	12.0	1.554± .035	11.93± .28
Low-protein	13.789± .048	14.0	1.571± .034	11.39± .27
High-oil	14.770± .051	14.0	1.758± .036	11.90± .25
Low-oil	12.806± .042	12.0	1.593± .030	12.44± .24

TABLE II.—*Type and variability of the four chemical-composition strains of Indian corn for 11 crops, 1905 to 1915*—Continued

CROP OF 1910

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High-protein	7.771±0.039	8.0	1.581±0.027	20.34±0.37
Low-protein	8.476± .051	8.5	1.678± .036	19.80± .44
High-oil	7.315± .030	7.5	1.019± .021	13.93± .30
Low-oil	8.094± .034	9.0	1.233± .024	15.23± .31
Circumference of ear, in inches:				
High-protein	6.034± .012	6.0	.469± .009	7.77± .15
Low-protein	6.730± .016	6.5	.546± .012	8.12± .17
High-oil	6.104± .014	6.0	.442± .011	7.24± .15
Low-oil	6.859± .014	7.0	.510± .010	7.43± .15
Weight of ear, in ounces:				
High-protein	8.415± .071	9.0	2.835± .051	33.69± .67
Low-protein	10.036± .090	11.0	3.460± .090	34.48±1.00
High-oil	7.600± .061	7.0	1.960± .043	25.82± .61
Low-oil	10.986± .090	13.0	3.060± .064	27.85± .62
Rows of kernels on ears:				
High-protein	13.345± .039	14.0	1.546± .028	11.58± .21
Low-protein	14.114± .059	14.0	1.995± .042	14.13± .30
High-oil	14.750± .060	14.0	1.936± .042	13.13± .29
Low-oil	13.280± .047	12.0	1.672± .033	14.82± .30

CROP OF 1911

Length of ear, in inches:				
High-protein	6.302±0.038	6.5	1.402±0.027	22.25±0.45
Low-protein	7.888± .045	8.5	1.411± .032	17.89± .42
High-oil	6.744± .034	6.5	1.216± .024	18.03± .37
Low-oil	6.486± .039	7.0	1.376± .027	21.21± .43
Circumference of ear, in inches:				
High-protein	5.356± .014	5.5	.510± .010	9.52± .19
Low-protein	6.026± .014	6.0	.502± .010	8.96± .19
High-oil	5.769± .014	6.0	.504± .010	8.74± .18
Low-oil	6.094± .014	6.5	.515± .010	8.45± .18
Weight of ear, in ounces:				
High-protein	4.980± .056	5.0	1.854± .040	37.24± .91
Low-protein	8.402± .071	10.0	2.336± .051	27.80± .65
High-oil	6.209± .050	6.0	1.672± .036	26.93± .63
Low-oil	6.323± .070	6.0	2.038± .050	32.23± .85
Rows of kernels on ears:				
High-protein	12.920± .046	12.0	1.541± .033	11.93± .26
Low-protein	13.700± .052	14.0	1.744± .037	10.08± .22
High-oil	15.350± .060	14.0	1.980± .042	12.89± .28
Low-oil	12.721± .060	12.0	1.693± .043	13.31± .33

TABLE II.—*Type and variability of the four chemical-composition strains of Indian corn for 11 crops, 1905 to 1915*—Continued

CROP OF 1912

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High-protein	7.992±0.028	8.5	1.356±0.028	16.97±0.36
Low-protein	8.550± .038	9.0	1.490± .027	17.43± .34
High-oil	7.210± .031	8.0	1.232± .022	17.09± .31
Low-oil	7.752± .032	11.3	1.180±.023	15.22± .32
Circumference of ear, in inches:				
High-protein	5.850± .014	6.0	.475± .010	8.12± .17
Low-protein	6.443± .014	6.50	.549± .010	8.52± .16
High-oil	6.066± .011	6.25	.459± .008	7.57± .14
Low-oil	6.619± .032	6.75	.575± .011	8.66± .17
Weight of ear, in ounces:				
High-protein	8.012±.059	10.0	1.985± .042	24.77± .57
Low-protein	10.962± .071	12.0	2.640± .051	24.08± .49
High-oil	7.852±.049	9.0	1.941± .035	24.72± .45
Low-oil	10.369± .073	10.0	2.561± .052	24.70± .54
Rows of kernels on ears:				
High-protein	12.866± .052	12.0	1.745± .037	13.56± .29
Low-protein	13.794± .059	14.0	1.801± .042	13.05± .26
High-oil	14.700± .045	14.0	1.788± .032	12.16± .22
Low-oil	12.448± .053	12.0	1.817± .038	14.60± .31

CROP OF 1913

Length of ear, in inches:				
High-protein	7.438±0.035	8.0	1.214±0.025	16.32±0.33
Low-protein	8.051± .041	8.5	1.397± .029	17.35± .37
High-oil	6.582± .033	6.5	1.178± .023	17.90± .36
Low-oil	7.026± .033	7.5	1.263± .023	17.98± .32
Circumference of ear, in inches:				
High-protein	5.593± .019	5.5	.589± .013	10.53± .24
Low-protein	5.956± .017	6.0	.578± .012	9.70± .21
High-oil	5.395± .014	5.5	.493± .010	9.14± .18
Low-oil	6.380± .016	6.5	.604± .011	9.47± .18
Weight of ear, in ounces:				
High-protein	6.754± .051	6.0	1.708± .036	25.29± .57
Low-protein	8.221± .060	9.0	1.890± .042	22.99± .55
High-oil	5.604± .043	6.0	1.437± .030	25.64± .58
Low-oil	7.492± .057	8.0	2.000± .040	26.70± .59
Rows of kernels on ears:				
High-protein	13.008± .052	12.0	1.782± .037	13.70± .29
Low-protein	14.260± .060	14.0	1.914± .042	13.42± .31
High-oil	14.512± .057	14.0	1.862± .040	12.83± .28
Low-oil	13.010± .053	12.0	1.842± .038	14.16± .29

TABLE II.—*Type and variability of the four chemical-composition strains of Indian corn for 11 crops, 1905 to 1915*—Continued.

CROP OF 1914

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High-protein	7.245±0.033	7.5	1.279±0.024	17.65±0.33
Low-protein	8.037± .041	8.5	1.368± .029	17.02± .37
High-oil	6.423± .035	6.5	1.248± .025	19.43± .40
Low-oil	6.985± .032	7.5	1.200± .022	17.18± .33
Circumference of ear, in inches:				
High-protein	5.287± .012	5.3	.441± .008	8.34± .17
Low-protein	5.918± .014	6.0	.474± .010	8.01± .17
High-oil	5.282± .013	5.5	.466± .009	8.82± .18
Low-oil	6.162± .015	6.5	.544± .010	8.83± .17
Weight of ear, in ounces:				
High-protein	6.396± .044	6.0	1.499± .031	23.44± .51
Low-protein	8.284± .068	9.0	2.170± .048	26.19± .62
High-oil	5.207± .043	5.0	1.417± .030	27.21± .63
Low-oil	7.711± .054	7.0	1.863± .038	24.16± .52
Rows of kernels on ears:				
High-protein	13.360± .046	14.0	1.668± .033	12.48± .25
Low-protein	14.402± .063	14.0	2.048± .045	14.22± .32
High-oil	14.489± .061	16.0	1.936± .043	13.00± .29
Low-oil	12.684± .044	12.0	1.552± .031	12.24± .25

CROP OF 1915

Length of ear, in inches:				
High-protein	7.176±0.029	7.5	1.173±0.021	16.35±0.29
Low-protein	7.859± .034	8.0	1.231± .024	15.66± .31
High-oil	7.358± .028	8.0	1.071± .020	14.56± .28
Low-oil	7.103± .035	8.0	1.148± .025	16.16± .35
Circumference of ear, in inches:				
High-protein	5.674± .010	5.75	.412± .007	7.26± .13
Low-protein	6.125± .016	6.50	.583± .011	9.52± .19
High-oil	5.781± .012	5.75	.468± .009	8.10± .16
Low-oil	6.455± .017	6.50	.592± .012	9.17± .19
Weight of ear, in ounces:				
High-protein	7.076± .044	7.0	1.669± .031	23.59± .47
Low-protein	8.685± .071	10.0	2.395± .050	27.58± .62
High-oil	7.361± .049	7.0	1.801± .035	24.47± .50
Low-oil	8.073± .072	10.0	2.294± .051	28.42± .68
Rows of kernels on ears:				
High-protein	13.986± .041	14.0	1.588± .029	11.35± .21
Low-protein	15.038± .053	16.0	1.896± .037	12.61± .25
High-oil	15.360± .047	16.0	2.262± .047	14.73± .31
Low-oil	14.034± .053	14.0	1.712± .037	12.20± .27

MEAN LENGTH OF EARS

In the first year (1905) we find that the means in length for any two of the strains are significantly different. The smallest difference that exists is 0.27 ± 0.056. We thus note that the smallest difference is about five times the probable error. The average difference in the means is about nine times the probable error of any difference between two means.

Having thus found in the 1905 crop significant differences when the differences are judged by probable errors, we very naturally inquire how persistently these differences are maintained and to what extent they are accentuated under continued selection for chemical composition. In these considerations we must not lose sight of the differences in soil conditions, such as we have on Experiment Station plots, and

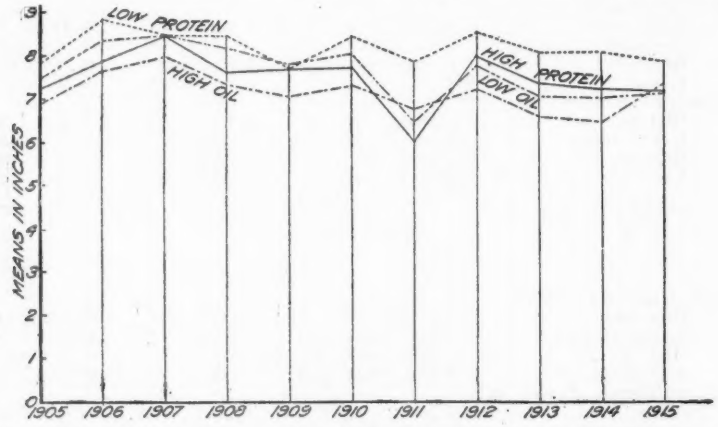

FIG. 1.—Graphs showing the mean length of the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

differences in seasonal conditions—that is to say, it should be kept in mind in considering these results that the various strains have occupied different plots of ground in different years and that there has been no special attempt to maintain uniform or comparable soil conditions among these breeding plots.

In figure 1 is shown graphically the mean values of length of ears in the four strains. It may be noted from these graphs that the order of magnitude of 1905 was maintained with slight exception till 1911. The year 1911 was an abnormal one characterized by lack of moisture at the time when the corn was much in need of moisture. The high-protein and the low-oil strains changed positions in 1912, and these two strains have maintained the new order through 1915. In 1915 the high-oil surpassed the high-protein and the low-oil strain, but it is not unlikely that this is only a seasonal fluctuation. While there have been

marked seasonal fluctuations in the mean length of ears for each of these strains, there is no marked regular change in the length of the ear for any strain. From the graphs in figure 1 there is, however, at least some evidence that, on the whole, the mean length of ears has been smaller during the second half of the period 1905–1915, than during the first half of the period. But it seems in explanation of this, that in the second half of the period there were at least three years in which the length of ears showed decidedly the effects of abnormal seasons.

There has been one progressive change worth noting, in that the mean lengths of ears for the high-protein strain for the past four years maintained a position above the low-oil strain. The differences between the mean lengths of ears in the latter half of the period 1905–1915 are slightly larger, but hardly significantly larger than those that existed in the earlier part of the period.

Since the probability that a given order of four elements in a trial under pure chance is 1 to 24, we note that there is a decided tendency to maintain order in mean length of ears, although there are a few exceptions.

MEAN CIRCUMFERENCE OF EARS

In the first year (1905) we find significant differences in the means except possibly for the case of the low-protein and the low-oil strains. For this pair we find a difference of 0.14 ± 0.03. While, under random sampling, we should probably ascribe at least some slight significance to such a difference, it is doubtful whether the difference is large enough to persist regularly under differences of seasons and soil. But, based on 11 years' experience, we find that the low-protein strain has always shown a smaller mean circumference than the low-oil strain, except in the one year (1908) when the two were substantially equal.

We note from figure 2 the regularity with which the order of 1905 has been maintained. The order for circumference of ears has been at least as well maintained as that for the length of ears, and perhaps a little more persistently. Figure 2 shows that the mean circumference of the high-oil strain was lower than that of the high-protein strain in the year 1913 only.

As to progressive changes, it is true, on the whole, that each of these strains shows a smaller mean circumference in the second half of the period 1905–1915 than in the first half, but it is not unlikely that this is due to seasonal fluctuations. What is more important for our purposes is to note that the mean differences between mean values are no more pronounced during the second half than during the first half of the period. That is to say, the differences existing in 1905 have well been maintained, considering the changes of soils and seasons, but they have not been decidedly increaeds since 1905 by the selections for chemical composition.

MEAN WEIGHT OF EARS

In 1905 there appeared to be no significant difference in weight of ears between the high-protein and the high-oil strains, and no significant difference between the low-protein and the low-oil. The high-protein and the high-oil were significantly different in weight of ears from the low-protein and the low-oil. These two classes seem to persist well under differences of season and soil, as shown by the graphs of figure 3.

In regard to progressive changes in weight, there is no doubt that, on the whole, the mean weight of the ears for each strain have been less

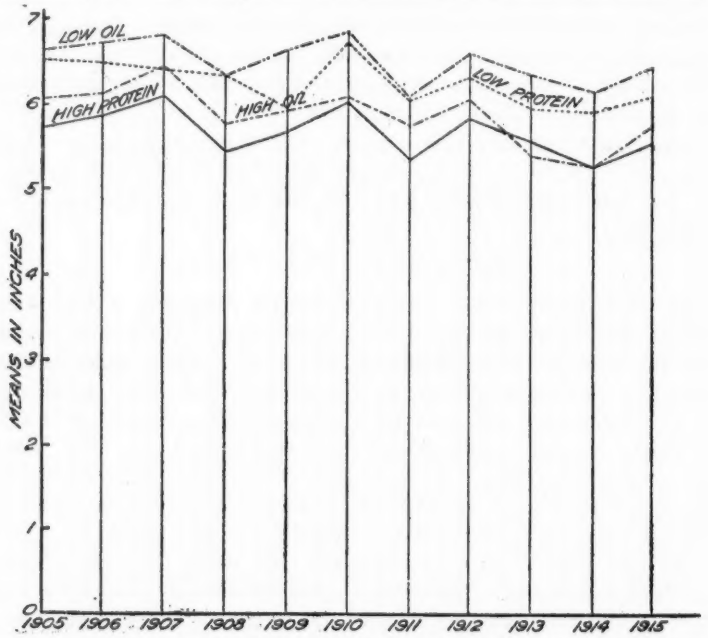

FIG. 2.—Graphs showing the mean circumference of the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

during the second half of the period 1905–1915 than during the first half of the period; that this is, however, merely in response to abnormal seasons is shown by the fact that the ears are particularly light for the crops of 1911, 1913, and 1914. It is important to note that the selection for chemical composition has probably neither increased nor decreased significantly the differences in the mean weight of ears during the period 1905–1915.

MEAN NUMBER OF ROWS OF KERNELS ON EARS

In the year 1905 there was a significant difference in the number of rows of kernels on ears. Figure 4 shows that the same order of magnitude

of number of rows of kernels has been invariably maintained throughout 11 years, except the years 1913 and 1915, when the low-oil changed

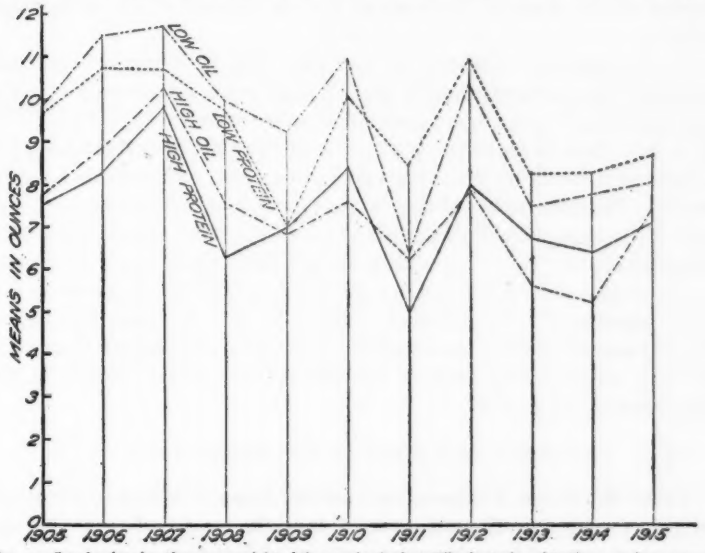

FIG. 3.—Graphs showing the mean weight of the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

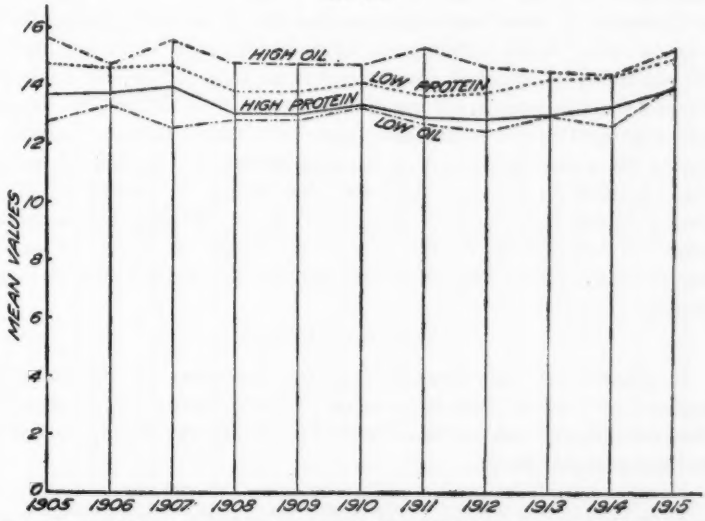

FIG. 4.—Graphs showing the mean number of rows of kernels in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

places with the high-protein strain. The differences, however, are insignificant in these years. As the character (rows of kernels) is deter-

mined by inherent tendencies and is less susceptible to external or environmental influences than the other characters considered, we should expect smaller seasonal fluctuations than in the case of the other characters.

As to progressive changes, we may note that while the low-oil strain seemed to tend toward a 12-row type for some years, it appears that in the 1910, 1913, and 1915 crops 14 rows of kernels are the modal value. That is to say, there is no longer good evidence that the low-oil strain is approaching a condition where the ears have 12 rows of kernels as a modal value. The differences existing in 1905 have been well maintained, except in the case of the high-protein and low-oil strains and we have indicated above that these two strains did not differ significantly in several recent crops. It is fair to say in a general way that the differences in the mean number of rows of kernels existing in 1905 have not been significantly accentuated by the selection for chemical composition from 1905 to 1915, although the mean of the differences is slightly greater in the latter half of the period.

GENERAL STATEMENT ABOUT DISTINCT TYPES

Taken as a whole, it is found that distinct types, as shown by the mean length of ears, the circumference of ears, the weight of ears, and the number of rows of kernels, are so well established that in most cases we may assign an order of magnitude that persists well in such changes of environment as have been experienced in the 11 years of planting from 1905 to 1915. While certain progressive changes have been noted above, the selections for chemical composition from 1905 to 1915 have not increased the difference in the mean values to such an extent that we are able to assert that the strains differ more with respect to these characters during the second half of the period than during the first half, although they certainly do not as a whole differ less during the second half than during the first half. In fact, as stated above, the differences of the mean length of ears and the number of rows of kernels are larger, by an insignificant amount, during the second half than during the first half of the period.

STANDARD DEVIATIONS

In general, the differences in standard deviations for the different strains compared to the corresponding probable errors are much smaller than the differences in the mean values for the different strains compared to their probable errors.

Many of the differences in standard deviations do not persist well from year to year under differences of soils and seasons. Perhaps we may properly infer from figure 5, that, on the whole, of the four strains the low-protein strain has the largest standard deviation in length of ears, and the high-oil strain has the smallest standard deviation; but there are

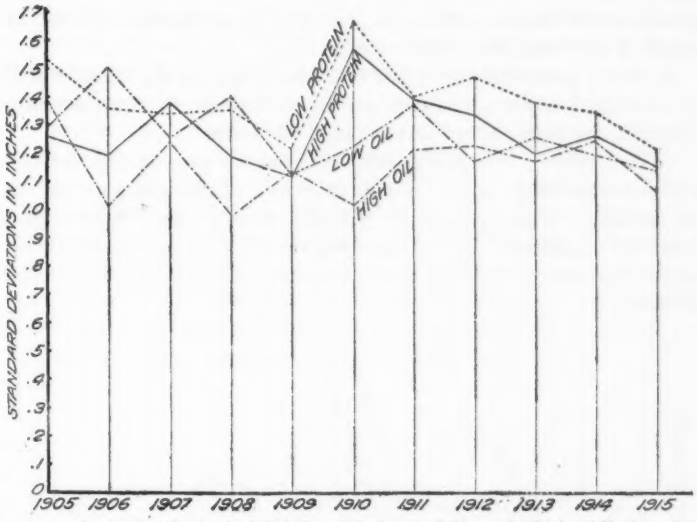

FIG. 5.—Graphs showing the standard deviation of the length of the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

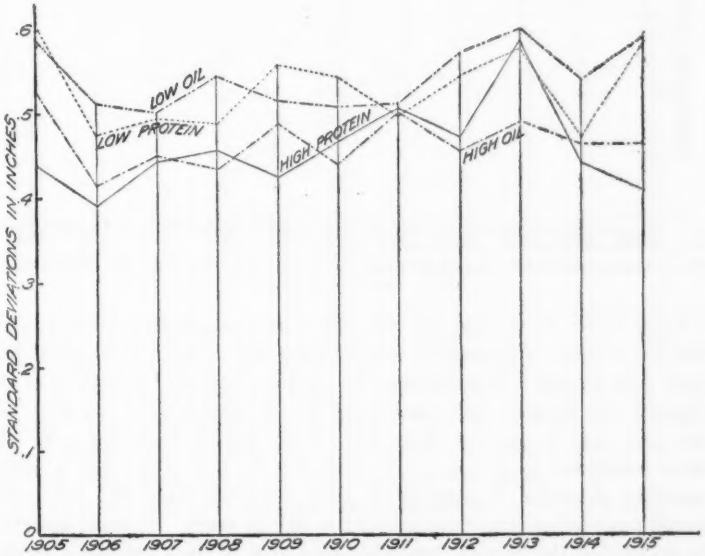

FIG. 6.—Graphs showing the standard deviation of the circumference of the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

some exceptions to this statement. At least we may state that the low-protein strain has for each of the 11 crops a larger standard deviation in length of ears than the high-oil strain.

As shown graphically on figure 6, we find that on the whole the low-oil and the low-protein strains are more variable in circumference of ears than the high-protein and the high-oil strains.

From figure 7 it is pretty clear that the low-protein and the low-oil strains are decidedly more variable in weight of ears than are the other two strains. When judged by probable errors, these differences are decidedly significant, and of such magnitude that we expect them to persist from year to year if soil and seasonal conditions are not extremely different.

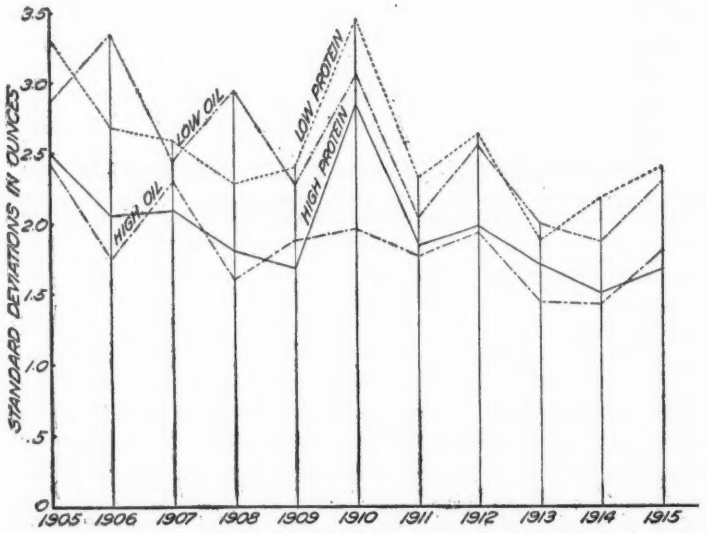

FIG. 7.—Graphs showing the standard deviation of the weight of the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

From figure 8 we note that the differences of standard deviations of number of rows of kernels for strains have not in general persisted well from year to year. For instance, in 1905 the standard deviation of the high-oil was greater than that of the low-oil strain by 0.31 ± 0.06, but the next year it was less than that of the low-oil by 0.09 ± 0.06. To have concluded from 0.31 ± 0.06 that the high-oil strain has a larger standard deviation in number of rows of kernels than the low strain would have led us into error in 2 out of the 11 years. It may, however, be noted that the high-oil strain has each year of the 11 shown a greater standard deviation than the high-protein strain.

Since the standard deviations, as shown in figures 5 to 8, do not show such an orderly arrangement as the corresponding mean values shown by

figures 1 to 4 and as the standard deviations have the smaller probable errors, we very naturally inquire for a plausible explanation of these results. Shall we conclude that the mean value is more stable and characterizes the strain better than the standard deviation does? To be sure, we often give a mean value to characterize a type; but in accord with what is stated above about these four strains of corn, the ratio of their differences of means to the probable errors of such differences are in general much greater than the ratio of the differences of their standard deviations to corresponding probable errors. In more definite form it is found that the ratio of the average difference of means in a crop to the average of the corresponding probable errors varies from 12 in the case of length of ears to 23 in the case of circumference of ears. On the other hand, the ratio of average differences in standard deviations in a crop to the average of the corresponding probable errors varies from 3.5 in the

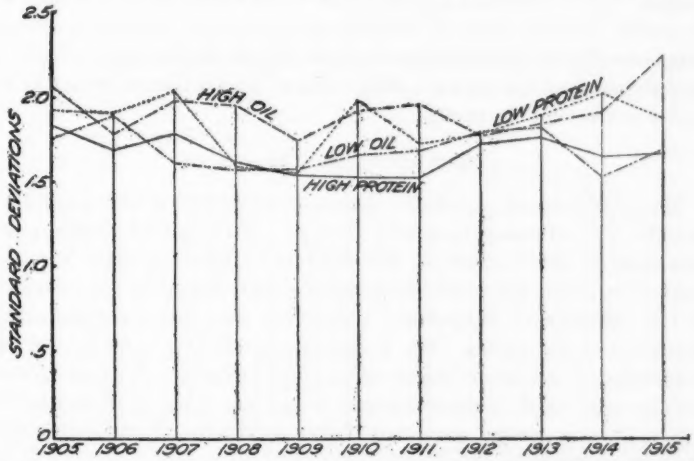

FIG. 8.—Graphs showing the standard deviation of the rows of kernels on the ears in the four Illinois strains of Indian corn for 11 crops, 1905–1915.

case of rows of kernels to 7 in the case of weight of ears. Incidentally, in the latter case, we find that the standard deviation is strikingly higher for the low-protein and the low-oil than for the high-protein and the high-oil strains, and that this difference persists without exception for the 11 crops. We should recognize, therefore, that the standard deviations of the four strains for a given year differ much less when compared with their probable errors than do the corresponding means. Hence, we should expect much less tendency to maintain an order of values of standard deviations than of means. If, on the other hand, the mean values were close together, and the standard deviations were significantly different, we could characterize strains better by standard deviations than by means.

Stated in another form, the differences of standard deviations of the four strains when taken as a whole are not large enough to separate the strains nearly so well as the differences of means separate them, although the standard deviations separate the strains well with regard to some of the four characters. For example, we distinguish the high-protein and the high-oil strains very effectively from the low-protein and the low-oil strains by differences of standard deviations in weight of ears. The fact that differences in standard deviations do not enable us to distinguish the strains so well as the differences of means does not mean that the standard deviations are less stable from season to season for a given strain than are the means. In fact, taken as a whole, the standard deviations are considerably less variable from season to season than the corresponding means. This is in accord with the fact that the probable errors of standard deviations are only about 0.7 those of corresponding means. We are justified in putting the above statement a little stronger by saying that the ratio of fluctuations of standard deviations actually experienced to the probable errors of standard deviations are less for these four strains than the corresponding ratios of fluctuations of means to the probable errors in the means.

COEFFICIENTS OF VARIABILITY

The coefficients of variability do not in any marked way maintain a definite order of values from year to year. We prepared graphic representations of the coefficients, but hesitate to take the space for their publication, since the conclusions drawn consist largely in the statement of the existence of insignificant differences that may be obtained by inspection of the tables. For length of ears these graphs gave a fair illustration of as many crossings as we should expect under pure chance. On the other hand, in circumference of ears the low-protein and low-oil strains have in general somewhat higher coefficients of variability than the high-oil strain.

When we compare differences of coefficients of variability with their probable errors, the differences in a fair number of cases are significant when judged by the usual requirements in regard to random sampling. But these differences are generally insufficient to withstand changes of season and soil. Further, we find that the ratio of the average of the differences of coefficients of variability in a season to the average of the probable errors in such differences varies from 2.7 in the case of rows of kernels to 3.8 in the case of weight of ears. The corresponding ratios of 12 and 23 given above for means show a striking contrast. This accounts for the maintenance of a pretty regular order for mean values, while no considerable degree of regularity is maintained among coefficients of variability. It seems that to maintain any considerable regularity from one season to another the differences must be larger, compared to prob-

able errors, than those which exist in the case of these coefficients of variability.

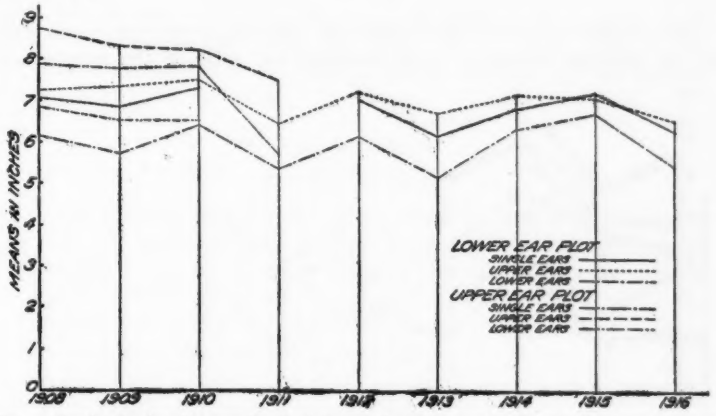

FIG. 9.—Graphs showing the mean length of the ears in the two-ear strains of Indian corn, 1908–1916.

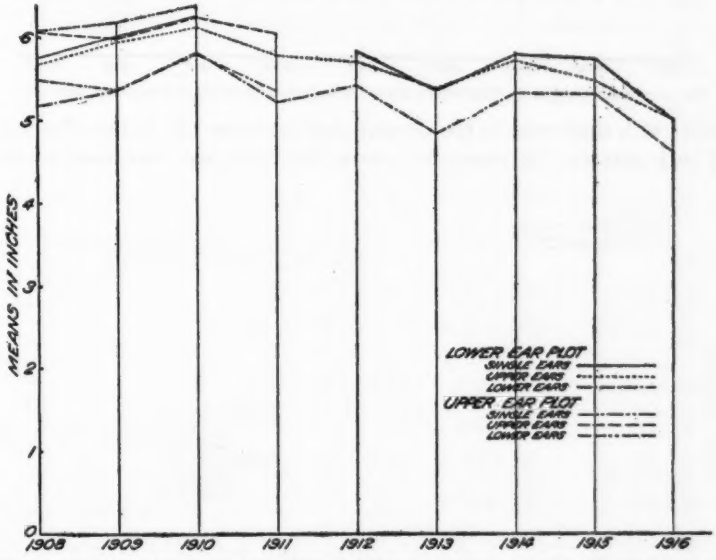

FIG. 10.—Graphs showing the mean circumference of the ears in the two-ear strains of Indian corn, 1908–1916.

TWO-EAR STRAINS

Table III gives the means, standard deviations, coefficients of variability, and corresponding probable errors, for length of ears, circumference of ears, weight of ears, and number of rows of kernels on ears for the two-ear strains.

COMPARISON OF UPPER AND LOWER EARS ON THE UPPER- AND LOWER-EAR PLOTS

The "upper-ear plots" were started by selecting seed from upper ears for the purpose primarily of determining the ratio of the number of

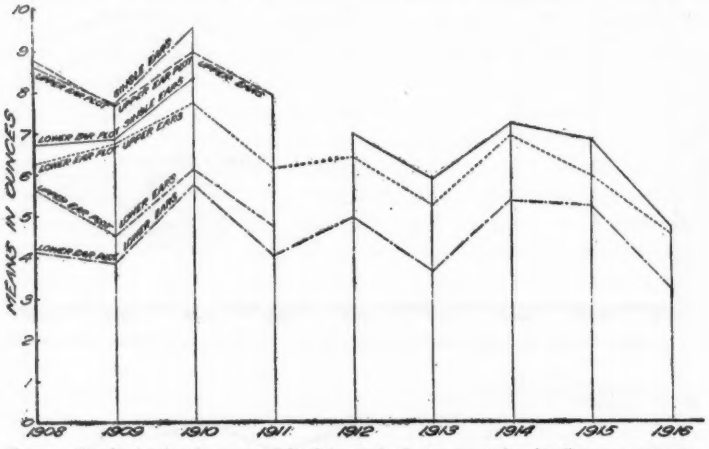

FIG. 11.—Graphs showing the mean weight of the ears in the two-ear strains of Indian corn, 1908–1916.

stalks with single ears to the number that have two ears in the offspring of such parents. In succeeding years, the upper ears continued to be

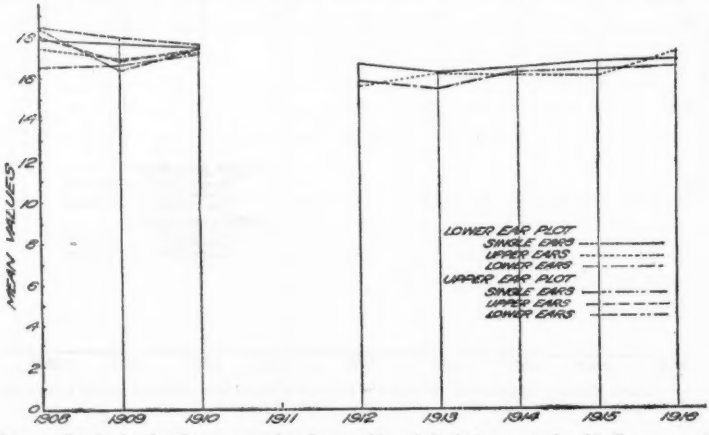

FIG. 12.—Graphs showing the mean number of rows of kernels in the two-ear strains of Indian corn, 1908–1916.

selected for planting. This perhaps defines sufficiently what is called the "upper-ear plots." Similarly on the "lower-ear plots" the lower ears were selected for planting. In the present paper we are not concerned with the primary purposes of the experiment, but with the effects

of the selections on the four physical characters of ears mentioned above.

Our data on the upper-ear plots cover four crops, 1908 to 1911. Our data on the lower-ear plots cover nine crops, 1908 to 1916, with the one exception of the single ears for 1911, owing to the fact that the records are not available for that case.

DIFFERENCES IN MEANS

[Table III and fig. 9 to 12]

It is true in every case that the upper ears have a significantly larger mean value in length, weight, and circumference than have the corresponding lower ears of the same stalks. This fact stands out prominently in the graphic representations of figures 9 to 12.

In mean length of ears these differences range from 5 to 30 per cent of the mean length of the shorter group of ears.

In mean weight of ears the differences range from 14 to 70 per cent of the mean length of the lighter group of ears.

In mean circumference of ears the differences range from a little less than 5 to 13 per cent of the mean circumference of the smaller group of ears.

TABLE III.—*Type and variability of the two-ear strains of Indian corn*

UPPER-EAR PLOT, CROP OF 1908

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Single ears	7.870±0.054	9.0	1.750±0.038	22.24±0.51
Upper ears	8.739± .052	8.5	.956± .037	10.94± .42
Lower ears	6.840± .072	7.5	1.344± .052	19.65± .77
Circumference of ear, in inches:				
Single ears	6.067± .020	6.0	.630± .014	10.38± .24
Upper ears	6.060± .025	5.75	.454± .018	7.49± .29
Lower ears	5.479± .030	5.50	.533± .021	9.73± .40
Weight of ear, in ounces:				
Single ears	8.64 ± .11	10.0	2.986± .071	34.57± .97
Upper ears	8.786± .098	9.0	1.658± .070	18.88± .81
Lower ears	5.69 ± .13	6.0	2.034± .091	35.75±1.68
Rows of kernels on ear:				
Single ears	18.35 ± .086	18.0	2.516± .060	13.71± .34
Upper ears	18.03 ± .14	18.0	2.55 ± .10	14.05± .56
Lower ears	18.25 ± .20	18.0	2.74 ± .14	15.04± .78

TABLE III.—*Type and variability of the two-ear strains of Indian corn*—Continued

UPPER-EAR PLOT, CROP OF 1909

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Single ears	7.775±0.043	8.0	1.085±0.030	13.96±0.40
Upper ears	8.325± .062	8.5	.897± .043	10.77± .53
Lower ears	6.512± .097	6.5	1.349± .065	20.72±1.10
Circumference of ears, in inches:				
Single ears	6.183± .020	6.0	.512± .014	8.42± .24
Upper ears	5.976± .028	6.0	.408± .020	6.83± .34
Lower ears	5.373± .036	5.5	.485± .025	9.03± .48
Weight of ear, in ounces:				
Single ears	7.719± .087	8.0	2.166± .061	28.06± .86
Upper ears	7.69 ± .12	8.0	1.622± .084	21.09±1.10
Lower ears	4.51 ± .14	4.0	1.810± .098	40.11±2.50
Rows of kernels on ears:				
Single ears	17.91 ± .10	18.0	2.482± .071	13.86± .41
Upper ears	16.76 ± .16	16.0	2.30 ± .11	13.72± .72
Lower ears	16.32 ± .18	18.0	2.41 ± .13	12.93± .80

UPPER-EAR PLOT, CROP OF 1910

Length of ear, in inches:				
Single ears	7.820±0.057	9.0	1.592±0.040	20.36±0.53
Upper ears	8.268± .056	8.0	1.021± .040	12.35± .48
Lower ears	6.522± .079	7.0	1.364± .056	20.91± .89
Circumference of ear, in inches:				
Single ears	6.376± .019	6.5	.526± .014	8.25± .22
Upper ears	6.260± .025	6.0	.459± .018	7.33± .18
Lower ears	5.784± .032	5.5	.529± .023	9.15± .40
Weight of ear, in ounces:				
Single ears	9.57 ± .11	11.0	2.957± .079	30.91± .90
Upper ears	8.99 ± .12	9.0	2.205± .087	24.5 ±1.0
Lower ears	6.13 ± .14	6.0	2.128± .099	34.7 ±1.8
Rows of kernels on ear:				
Single ears	17.542± .091	18.0	2.366± .064	13.49± .37
Upper ears	17.26 ± .14	16.0	2.54 ± .10	14.73± .60
Lower ears	17.31 ± .15	16.0	2.27 ± .11	13.12± .64

UPPER-EAR PLOT, CROP OF 1911

Length of ear, in inches:				
Single ears	.....	.....	.....	.....
Upper ears	7.537±0.010	7.5	1.319±0.070	17.50±0.94
Lower ears	5.715± .012	6.0	1.298± .083	22.71± .13
Circumference of ear, in inches:				
Single ears	.....	.....	.....	.....
Upper ears	6.066± .041	6.0	.535± .029	8.82± .48
Lower ears	5.339± .049	5.0	.603± .035	11.29± .67
Weight of ear, in ounces:				
Single ears	.....	.....	.....	.....
Upper ears	7.942± .015	9.0	1.941± .011	24.44± .15
Lower ears	4.716± .022	3.0	2.031± .016	43.10± .40

TABLE III.—*Type and variability of the two-ear strains of Indian corn*—Continued

LOWER-EAR PLOT, CROP OF 1908

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Single ears	7.056±0.043	8.0	1.295±0.030	18.35±0.44
Upper ears	7.238± .097	7.5	1.227± .068	16.95± .96
Lower ears	6.14 ± .10	6.0	1.188± .071	19.3 ±1.2
Circumference of ear, in inches:				
Single ears	5.741± .020	6.0	.574± .014	10.00± .25
Upper ears	5.671± .051	5.75	.575± .036	10.14± .64
Lower ears	5.192± .046	5.25	.514± .032	10.09± .64
Weight of ear, in ounces:				
Single ears	6.740± .078	7.0	2.176± .055	32.28± .90
Upper ears	6.26 ± .20	5.0	2.24 ± .14	35.7 ±2.5
Lower ears	4.11 ± .17	3.0	1.79 ± .12	43.6 ±3.4
Rows of kernels on ear:				
Single ears	17.79 ± .10	18.0	2.55 ± .071	14.32± .41
Upper ears	17.35 ± .20	16.0	2.16 ± .14	12.45± .82
Lower ears	16.49 ± .23	16.0	2.20 ± .16	13.3 ±1.0

LOWER-EAR PLOT, CROP OF 1909

Length of ear, in inches:				
Single ears	6.834±0.039	8.0	1.143±0.028	16.73±0.42
Upper ears	7.350± .061	7.5	.901± .043	12.26± .59
Lower ears	5.701± .078	5.5	1.176± .055	20.6 ±1.0
Circumference of ear, in inches:				
Single ears	6.014± .019	6.0	.552± .013	9.18± .23
Upper ears	5.932± .032	6.0	.464± .022	7.82± .37
Lower ears	5.356± .041	5.5	.546± .029	10.19± .55
Weight of ear, in ounces:				
Single ears	6.87 ± .11	7.0	2.228± .078	32.4 ±1.3
Upper ears	6.763± .14	7.0	1.994± .099	29.5 ±1.5
Lower ears	3.88 ± .15	2.0	1.89 ± .11	48.7 ±3.2
Rows of kernels on ear:				
Single ears	17.63 ± .094	16.0	2.496± .066	14.16± .38
Upper ears	16.93 ± .16	16.0	2.28 ± .11	13.48± .67
Lower ears	16.60 ± .28	16.0	2.75 ± .20	16.5 ±1.2

LOWER-EAR PLOT, CROP OF 1910

Length of ear, in inches:				
Single ears	7.314±0.051	8.0	1.416±0.036	19.36±0.26
Upper ears	7.517± .039	8.0	1.088± .020	14.48± .38
Lower ears	6.405± .045	7.0	1.195± .032	18.66± .51
Circumference of ear, in inches:				
Single ears	6.272± .022	6.0	.587± .016	9.36± .25
Upper ears	6.122± .018	6.0	.476± .012	7.78± .20
Lower ears	5.816± .019	6.0	.480± .013	8.25± .23
Weight of ear, in ounces:				
Single ears	8.359± .12	5.0	2.853± .085	34.1 ±1.1
Upper ears	7.770± .087	7.0	2.124± .061	27.32± .85
Lower ears	5.793± .081	5.0	1.903± .057	32.8 ±1.1
Rows of kernels on ear:				
Single ears	17.44 ± .11	16.0	2.644± .076	15.15± .45
Upper ears	17.24 ± .10	16.0	2.674± .071	15.51± .42
Lower ears	17.07 ± .11	16.0	2.584± .076	15.14± .45

TABLE III.—*Type and variability of the two-ear strains of Indian corn*—Continued

LOWER-EAR PLOT, CROP OF 1911

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Single ears				
Upper ears	6.462±0.087	5.5	1.357±0.062	21.00±1.00
Lower ears	5.358± .091	5.5	1.358± .065	25.35±1.30
Circumference of ear, in inches:				
Single ears				
Upper ears	5.790± .078	6.0	.532± .056	9.19± .50
Lower ears	5.216± .091	5.25	.561± .065	10.75± .65
Weight of ear, in ounces:				
Single ears				
Upper ears	6.18 ± .170	6.0	1.764± .120	28.5 ±1.4
Lower ears	4.04 ± .130	3.0	1.677± .089	41.5 ±2.6
CROP OF 1912				
Length of ear, in inches:				
Single ears	7.056±0.048	7.5	1.233±0.034	17.47±0.49
Upper ears	7.250± .066	7.0	1.900± .047	26.21± .67
Lower ears	6.176± .075	6.5	2.100± .053	34.00± .84
Circumference of ear, in inches:				
Single ears	5.853± .020	6.0	.523± .014	8.94± .24
Upper ears	5.700± .015	5.75	.417± .010	7.32± .19
Lower ears	5.427± .014	5.5	.392± .010	7.22± .19
Weight of ear, in ounces:				
Single ears	7.004± .088	6.0	2.053± .062	29.31± .96
Upper ears	6.429± .052	6.0	1.406± .037	21.87± .65
Lower ears	4.977± .052	5.0	1.245± .037	25.02± .79
Rows of kernels on ear:				
Single ears	16.560± .088	16.0	2.212± .062	13.61± .39
Upper ears	15.560± .069	16.0	1.990± .049	12.79± .32
Lower ears	15.822± .023	16.0	1.870± .016	11.82± .10
CROP OF 1913				
Length of ear, in inches:				
Single ears	6.202±0.061	6.0	1.394±0.043	22.48±0.75
Upper ears	6.741± .064	6.5	1.238± .046	18.37± .72
Lower ears	5.192± .069	5.0	1.257± .049	24.2 ±1.0
Circumference of ear, in inches:				
Single ears	5.359± .025	5.0	.581± .018	10.84± .35
Upper ears	5.374± .028	5.5	.528± .020	9.82± .39
Lower ears	4.844± .025	4.75	.454± .018	9.37± .39
Weight of ear, in ounces:				
Single ears	5.908± .093	6.0	1.641± .066	27.8 ±1.3
Upper ears	5.280± .083	5.0	1.411± .059	26.7 ±1.2
Lower ears	3.655± .093	3.0	1.173± .060	32.1 ±1.8
Rows of kernels on ears:				
Single ears	16.19 ± .13	16.0	2.486± .089	15.35± .58
Upper ears	16.10 ± .13	16.0	2.252± .090	13.99± .58
Lower ears	15.42 ± .15	14.0	2.07 ± .10	13.42± .69

TABLE III.—*Type and variability of the two-ear strains of Indian corn*—Continued

CROP OF 1914

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ears, in inches:				
Single ears	6.855±0.061	8.0	1.473±0.043	21.49±0.71
Upper ears	7.190± .031	7.5	1.052± .022	14.63± .32
Lower ears	6.340± .031	6.5	1.015± .022	16.01± .36
Circumference of ear, in inches:				
Single ears	5.789± .024	5.75	.574± .017	9.92± .30
Upper ears	5.696± .014	5.75	.456± .010	8.01± .17
Lower ears	5.427± .014	5.50	.440± .010	8.11± .18
Weight of ear, in ounces:				
Single ears	7.23 ± .10	7.0	2.246± .070	31.1 ±1.0
Upper ears	7.060± .048	7.0	1.553± .034	22.00± .51
Lower ears	5.376± .049	5.0	1.439± .035	26.77± .69
Rows of kernels on ear:				
Single ears	16.434± .097	16.0	2.245± .069	13.66± .42
Upper ears	16.004± .065	16.0	2.128± .046	13.30± .29
Lower ears	16.140± .066	16.0	2.060± .047	12.76± .30

CROP OF 1915

Length of ears, in inches:				
Single ears	7.220±0.075	7.5	1.288±0.053	17.84±0.79
Upper ears	7.107± .024	7.5	.900± .017	12.66± .24
Lower ears	6.718± .025	6.5	.939± .018	13.98± .27
Circumference of ears, in inches:				
Single ears	5.718± .028	5.75	.470± .020	8.22± .35
Upper ears	5.485± .011	5.5	.404± .008	7.37± .14
Lower ears	5.295± .011	5.5	.414± .008	7.82± .15
Weight of ear, in ounces:				
Single ears	6.860± .115	8.0	1.878± .081	27.4 ±1.3
Upper ears	5.981± .033	6.0	1.228± .024	20.53± .41
Lower ears	5.243± .036	5.0	1.285± .025	24.51± .50
Rows of kernels on ear:				
Single ears	16.69 ± .13	16.0	2.250± .095	13.48± .60
Upper ears	15.990± .055	16.0	2.086± .039	13.05± .25
Lower ears	16.282± .054	16.0	2.026± .038	12.44± .24

CROP OF 1916

Length of ears, in inches:				
Single ears	6.327±0.042	6.5	0.934±0.030	14.77±0.49
Upper ears	6.545± .047	6.5	1.057± .033	16.15± .52
Lower ears	5.441± .050	5.5	1.111± .035	20.42± .67
Circumference of ear, in inches:				
Single ears	4.995± .020	5.0	.444± .014	8.89± .29
Upper ears	5.011± .016	4.75	.369± .012	7.35± .23
Lower ears	4.615± .018	4.75	.413± .013	8.95± .25
Weight of ear, in ounces:				
Single ears	4.762± .087	4.0	1.776± .062	37.29±1.46
Upper ears	4.549± .054	4.0	1.143± .038	25.13± .87
Lower ears	3.270± .053	4.0	1.035± .037	31.64±1.25
Rows of kernels on ear:				
Single ears	16.249± .090	16.0	1.849± .063	11.37± .42
Upper ears	16.327± .095	16.0	2.070± .067	12.68± .42
Lower ears	16.14 ± .10	16.0	2.123± .074	13.15± .47

With respect to the number of rows of kernels on ears, no significant difference is shown to exist between the upper and the lower ears. While the upper-ear plots were continued for only four years, it seems that it may be of value to compare for these four years the upper ears of the upper-ear plots with the upper ears of the lower-ear plots and the lower ears of the upper-ear plots with the lower ears of the lower-ear plots. From such a comparison (see fig. 9 to 12) we may assert that in mean length of ears, circumference of ears, and weight of ears, the upper ears of the upper-ear plot are larger in each case than the corresponding upper ears of the lower-ear plot. The lower ears of the upper-ear plots exceed in mean length and weight the lower ears of the lower-ear plots, but in circumference no significant difference exists.

DIFFERENCES IN VARIABILITY

[Table III and fig. 13 to 16]

The standard deviations of length of ears have in general been only slightly different for the upper and lower ears of the lower-ear plots. In circumference of ears for the lower-ear plots it seems that the differences in standard deviation are insufficient to persist from season to season. In the weight of ears the standard deviations of the upper ears of the lower-ear plots have generally been significantly greater than those of the lower ears of the lower-ear plots. The year 1915 gives an exception to this rule. The standard deviations of the upper ears on the upper-ear plots for length of ears, weight of ears, and circumference of ears are in general smaller than the corresponding standard deviations of the lower ears on these plots.

The coefficients of variability for length and weight of the lower ears of the lower-ear plots are decidedly larger than the coefficients of variability for these characters in the upper ears of the lower-ear plots. Furthermore the coefficients of variability of length, circumference, and weight of the upper ears are larger for the lower-ear plots than for the corresponding upper-ear plots.

COMPARISON OF SINGLE EARS ON UPPER- AND LOWER-EAR PLOTS WITH THE UPPER AND LOWER EARS

[Table III and fig. 9 to 16]

DIFFERENCES OF MEANS

[Fig. 9 to 12]

The means of single ears for weight, length, and circumference are larger in each case than the corresponding means of the lower ears.

In length of ears the mean values of the upper ears are larger than those of the corresponding single ears in 10 out of 11 cases. To judge by probable errors, no more than half of these differences are significant.

But on the whole there seems to be some tendency for the upper ears to exceed the single ears in length.

In the circumference of ears the means of the single ears exceed the means of the upper ears in 8 out of 11 cases, but only 4 of these differences are significant when judged by probable errors.

In weight of ears, the means for the single ears exceed those for the upper ears in every case but one. Thus, it appears in a general way that single ears tend to be relatively heavier and larger in circumference, but shorter than upper ears.

In rows of kernels on ears the mean number for the single ears is larger in each case but one than that for the upper and lower ears, but three of these differences are so small as hardly to be regarded as significant when compared with probable errors.

DIFFERENCES IN VARIABILITY

[Table III and fig. 13 to 16]

With respect to the length of ears nothing very definite is to be inferred. In cir- cumference of ears, with a single exception in 22 cases, the standard deviation of the single ears exceeds that of upper and lower ears,and the difference is insignificant in this exceptional case.

In weight of ears the single ears have a greater standard deviation than the upper or lower ears in 21 out of 22 cases. In fact, so great is this difference that in some cases it looks as if the two frequency distributions of upper and lower ears might be combined to form the frequency distribution of single ears.

In length and weight of ears the coefficients of variability of the lower ears exceed those of the corresponding upper ears. In circumference of ears, the coefficient of variability of the lower ears either exceeds in each case that of the corresponding upper ears or differs from it by an insignificant amount.

ERECT- AND DECLINING-EAR STRAINS

Table IV gives the means, standard deviations, coefficients of variability, and the corresponding probable errors for the characters in question of the erect- and declining-ear strains.

Although we exhibit graphically the results on the erect- and declining-ear strains and those on the high- and low-ear strains on the same figures, we do so to save space, and not to make comparisons of the erect- and declining-ear strains with the high- and low-ear strains. Comparisons are made only between the erect- and declining-ear strains and between the high- and low-ear strains.

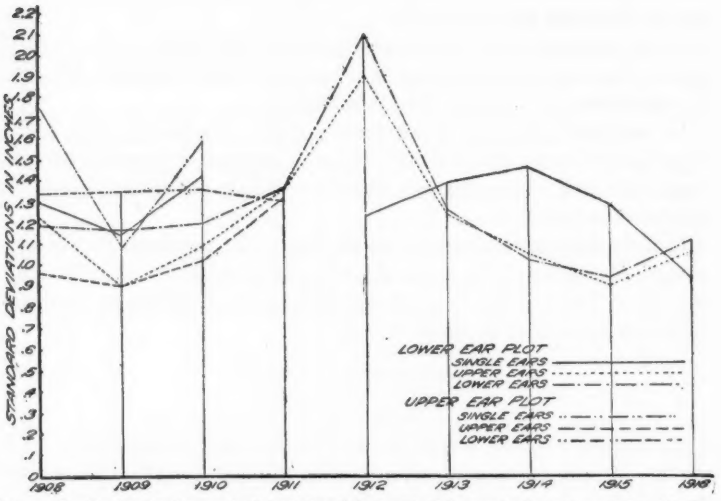

FIG. 13.—Graphs showing the standard deviation of the length of the ears in the two-ear strains of Indian corn, 1908–1916.

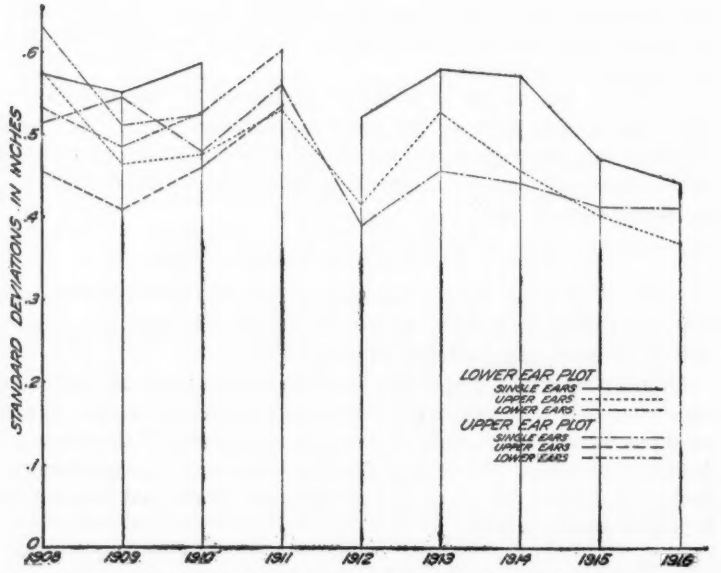

FIG. 14.—Graphs showing the standard deviation of the circumference of the ears in the two-ear strains of Indian corn, 1908–1916.

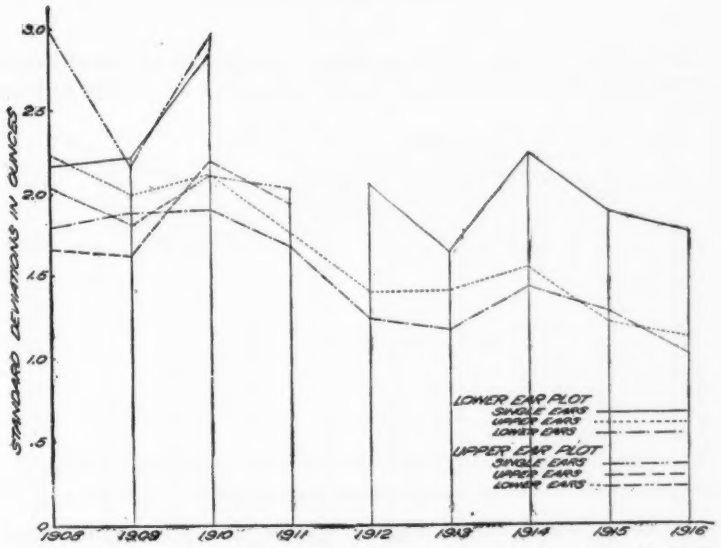

FIG. 15.—Graphs showing the standard deviation of the weight of the ears in the two-ear strains of Indian corn, 1908–1916.

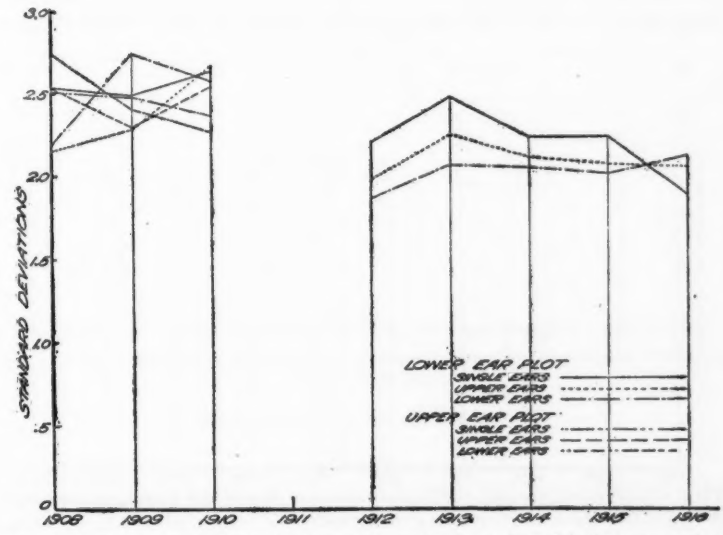

FIG. 16.—Graphs showing the standard deviation of the number of rows of kernels in the two-ear strains of Indian corn.

DIFFERENCES IN MEANS

[Fig. 17 to 20]

In 6 of the 10 years of this experiment we find that the mean lengths of the erect ears exceed those of the declining ears. In 7 of the 10 years,

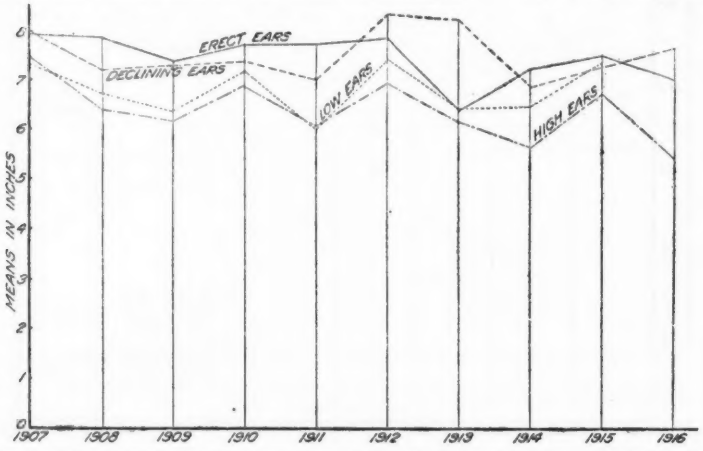

FIG. 17.—Graphs showing the mean length of the ears of the erect- and declining-ear strains of Indian corn.

the means of weights of erect ears exceed those of declining ears. In mean number of rows of kernels on ears, there is no significant difference

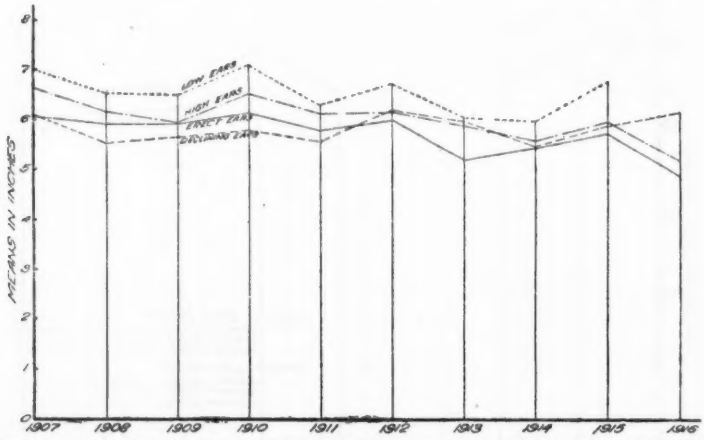

FIG. 18.—Graphs showing the mean circumference of the ears of the erect- and declining-ear strains of Indian corn.

between erect and declining ears. Taken as a whole it seems that no differences in means are large enough to persist well from season to season. The fact that the erect ears are on the whole, at least as heavy

as the declining ears is of special interest because of a natural suggestion that the ears decline on account of their weight.[1]

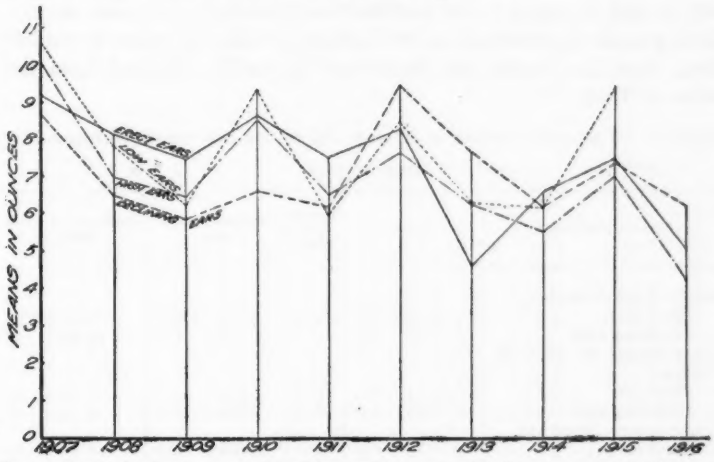

FIG. 19.—Graphs showing the mean weight of the ears of the erect- and declining-ear strains of Indian corn.

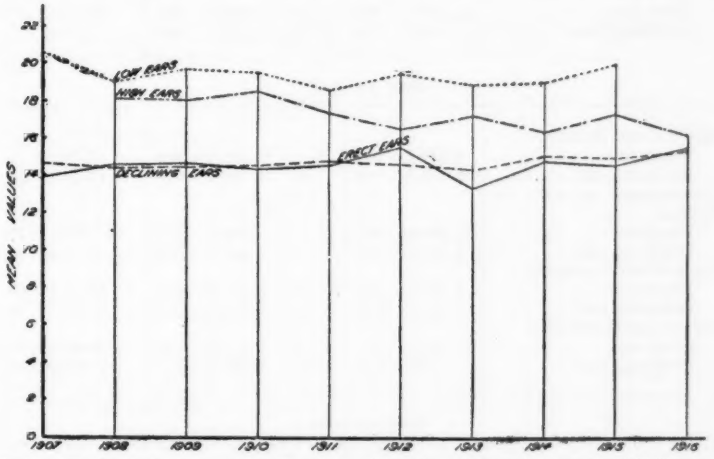

FIG. 20.—Graphs showing the mean number of rows of kernels on the ears of the erect- and declining-ear strains of Indian corn.

DIFFERENCES IN VARIABILITY

[Fig. 17 to 20]

In regard to the standard deviations it seems that no inference of value is to be drawn in regard to differences between erect and declining-ear strains. It seems that in about one-half of the cases the erect ears are

[1] SMITH, L. H. THE EFFECT OF SELECTION UPON CERTAIN PHYSICAL CHARACTERS IN THE CORN PLANT Ill. Agr. Exp. Sta. Bull. 132, p. 47-62, 5 p. 1909.

more variable than the declining, while the reverse is true for the remainder of the cases. The differences are in general of no significance. The same may be said in regard to the coefficients of variability, of which we prepared graphic representations but hesitate to take the space to exhibit them, since the conclusions drawn can be readily obtained from the values in Table IV.

TABLE IV.—*Type and variability of the erect- and declining-ear strains of Indian corn*

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
CROP OF 1907				
Length of ear, in inches:				
Erect ears	7.925±0.037	9.0	1.380±0.026	17.41±0.35
Declining ears	7.968± .053	9.0	1.575± .037	19.77± .50
Circumference of ears, in inches:				
Erect ears	6.053± .014	6.0	.519± .010	8.58± .17
Declining ears	6.086± .020	6.5	.568± .014	9.33± .23
Weight of ears, in ounces:				
Erect ears	9.191± .075	10.0	2.688± .053	29.25± .64
Declining ears	8.660± .110	9.0	2.953± .071	33.98± .99
Rows of kernels on ears:				
Erect ears	13.918± .054	14.0	1.900± .038	13.65± .28
Declining ears	14.688± .072	14.0	1.983± .052	13.50± .35
CROP OF 1908				
Length of ear, in inches:				
Erect ears	7.850±0.067	8.0	1.243±0.024	15.84±0.31
Declining ears	7.183± .031	7.0	1.109± .022	15.44± .31
Circumference of ear, in inches:				
Erect ears	5.900± .014	6.0	.500± .010	.848± .17
Declining ears	5.511± .013	5.5	.447± .009	8.11± .16
Weight of ear, in ounces:				
Erect ears	8.128± .067	8.0	2.132± .047	26.23± .62
Declining ears	6.485± .053	6.0	1.803± .037	27.80± .62
Rows of kernels on ears:				
Erect ears	14.560± .051	14.0	1.754± .036	12.05± .25
Declining ears	14.370± .056	14.0	1.880± .039	13.08± .28
CROP OF 1909				
Length of ear, in inches:				
Erect ears	7.366±0.033	8.0	1.246±0.023	16.92±0.32
Declining ears	7.278± .034	7.0	1.298± .024	17.83± .36
Circumference of ear, in inches:				
Erect ears	5.911± .013	6.0	.512± .009	.866± .17
Declining ears	5.647± .016	5.5	.570± .012	10.09± .20
Weight of ear, in ounces:				
Erect ears	7.442± .058	8.0	2.186± .041	29.37± .60
Declining ears	5.836± .056	6.0	1.916± .040	32.83± .75
Rows of kernels on ears:				
Erect ears	14.623± .053	14.0	1.927± .038	13.07± .26
Declining ears	14.429± .057	14.0	1.911± .040	13.24± .28

TABLE IV.—*Type and variability of the erect- and declining-ear strains of Indian corn*—Continued

CROP OF 1910

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Erect ears	7.691±0.031	8.0	1.065±0.022	13.85±0.29
Declining ears	7.350± .035	8.0	1.143± .024	15.55± .34
Circumference of ear, in inches:				
Erect ears	6.135± .013	6.0	.455± .009	7.42± .16
Declining ears	5.796± .015	6.0	.484± .011	8.35± .18
Weight of ear, in ounces:				
Erect ears	8.643± .068	9.0	2.267± .048	26.23± .59
Declining ears	6.598± .061	7.0	1.875± .043	28.42± .71
Rows of kernels on ears:				
Erect ears	14.314± .050	14.0	1.676± .035	11.71± .25
Declining ears	14.520± .056	14.0	1.765± .040	12.16± .28

CROP OF 1911

Length of ear, in inches:				
Erect ears	7.708±0.036	8.5	1.418±0.026	18.39±0.34
Declining ears	6.985± .036	7.5	1.312± .026	18.78± .38
Circumference of ear, in inches:				
Erect ears	5.785± .011	5.75	.457± .008	7.90± .15
Declining ears	5.575± .015	5.50	.510± .011	9.15± .19
Weight of ear, in ounces:				
Erect ears	7.480± .053	8.0	1.925± .038	25.74± .54
Declining ears	6.154± .069	6.0	1.700± .049	27.62± .81
Rows of kernels on ears:				
Erect ears	14.538± .049	14.0	1.877± .035	12.91± .26
Declining ears	14.758± .077	14.0	1.900± .055	12.87± .36

CROP OF 1912

Length of ear, in inches:				
Erect ears	7.821±0.037	8.5	1.379±0.021	17.63±0.29
Declining ears	8.294± .033	9.0	1.314±0.024	15.84± .29
Circumference of ear, in inches:				
Erect ears	5.998± .010	6.0	.467±0.007	7.79± .12
Declining ears	6.220± .012	6.0	.479±0.009	7.70± .15
Weight of ear, in ounces:				
Erect ears	8.255± .051	9.0	2.135±0.036	25.86± .47
Declining ears	9.436± .059	9.0	2.218±0.042	23.51± .47
Rows of kernels on ears:				
Erect ears	15.506± .044	14.0	1.844±0.031	12.15± .20
Declining ears	14.546± .048	14.0	1.845±0.034	12.86± .24

TABLE IV.—*Type and variability of the erect- and declining-ear strains of Indian corn*—Continued

CROP OF 1913

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Erect ears	6.338±0.044	6.5	1.311±0.031	20.68±0.51
Declining ears	8.182± .034	8.5	1.277± .024	15.61±0.30
Circumference of ear, in inches:				
Erect ears	5.205± .016	5.0	0.480± .011	9.22±0.22
Declining ears	5.969± .012	6.0	0.437± .008	7.32±0.14
Weight of ear, in ounces:				
Erect ears	4.565± .065	4.0	1.543± .046	33.80±1.12
Declining ears	7.661± .050	8.0	1.772± .035	23.13±0.49
Rows of kernels on ears:				
Erect ears	13.380± .065	12.0	1.598± .046	11.94±0.35
Declining ears	14.310± .169	14.0	1.811± .119	12.65±0.91

CROP OF 1914

Length of ear, in inches:				
Erect ears	7.197±0.038	7.5	1.198±0.027	16.65±0.39
Declining ears	6.849± .030	7.5	1.112± .022	16.24±0.32
Circumference of ear, in inches:				
Erect ears	5.464± .017	5.25	0.524± .012	9.590±0.23
Declining ears	5.482± .013	5.50	0.454± .009	8.281±0.17
Weight of ear, in ounces:				
Erect ears	6.567± .057	7.0	1.665± .041	25.35±0.66
Declining ears	6.145± .049	6.0	1.555± .035	25.31±0.61
Rows of kernels on ears:				
Erect ears	14.796± .033	14.0	1.970± .023	13.314±0.16
Declining ears	15.100± .061	14.0	1.936± .043	12.821±0.30

CROP OF 1915

Length of ear, in inches:				
Erect ears	7.455±0.030	8.0	1.220±0.021	16.36±0.29
Declining ears	7.212± .025	7.5	1.020± .018	14.14±0.25
Circumference of ear, in inches:				
Erect ears	5.728± .012	5.75	0.496± .009	8.66±0.15
Declining ears	5.856± .012	6.00	0.481± .008	8.22±0.15
Weight of ear, in ounces:				
Erect ears	7.449± .049	8.0	1.889± .035	25.36±0.50
Declining ears	7.344± .044	7.0	1.640± .031	22.33±0.45
Rows of kernels on ears:				
Erect ears	14.616± .044	14.0	1.768± .031	12.10±0.22
Declining ears	14.930± .070	14.0	2.116± .049	14.17±0.34

TABLE IV.—*Type and variability of the erect- and declining-ear strains of Indian corn*—Continued

CROP OF 1916

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
Erect ears	6.985±0.041	7.0	1.290±0.029	18.47±0.43
Declining ears	7.639± .034	7.5	1.141± .024	14.94±0.32
Circumference of ear, in inches:				
Erect ears	4.892± .014	5.0	.409± .010	8.37±0.20
Declining ears	5.599± .013	5.5	.438± .009	7.82±0.17
Weight of ear, in ounces:				
Erect ears	5.019± .061	5.0	1.459± .043	29.07±1.25
Declining ears	6.178± .048	7.0	1.417± .034	22.78±0.57
Rows of kernels on ears:				
Erect ears	15.573± .072	14.0	1.679± .051	11.52±0.35
Declining ears	15.420± .059	16.0	1.767± .059	11.46±0.27

HIGH- AND LOW-EAR STRAINS

Table V gives the means, standard deviations, coefficients of variability, and corresponding probable errors for the characters in question of the high- and low-ear strains.

DIFFERENCES IN MEANS

[Fig. 17 to 20]

The mean lengths of ears of the low-ear strain exceed in general slightly but significantly the mean lengths of ears of the high-ear strain, but there are two exceptions in nine years. The mean circumference of ears from the low-ear strain exceeds decidedly in each year the mean circumference of ears of the high-ear strain. The mean weight of ears of the low-ear strain exceeds the mean weight of the high-ear strain in seven of the nine years. Some of these differences would be regarded as unquestionably significant in the light of their probable errors, but the excess of the mean weights of low ears is not so well fixed but that in two seasons of the nine the mean weights of high ears exceed slightly those of the low ears. In mean number of rows of kernels on ears the low ears exceed the high ears in every case. This difference is decidedly significant.

DIFFERENCES IN VARIABILITY

[Fig. 21 to 24]

In length of ears it is doubtful if there is any significant difference in variability between the high- and low-ear strains. In circumference of ears the low-ear strain shows in general the greater variability. In weight of ears it is doubtful whether there is any significant difference

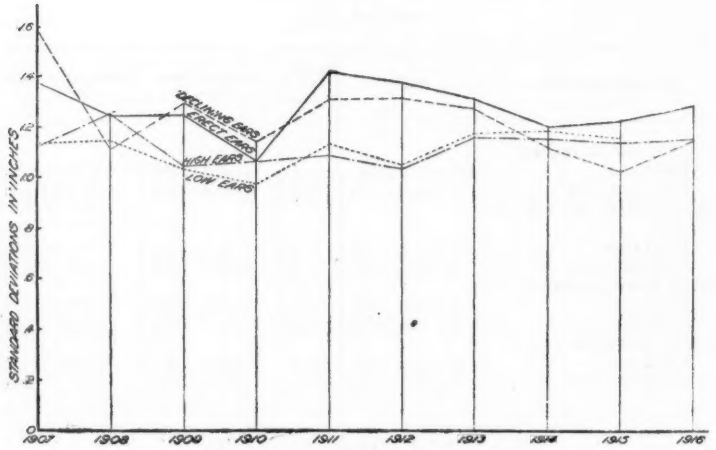

FIG. 21.—Graphs showing the standard deviation of the length of the ears of the high- and low-ear strains of Indian corn.

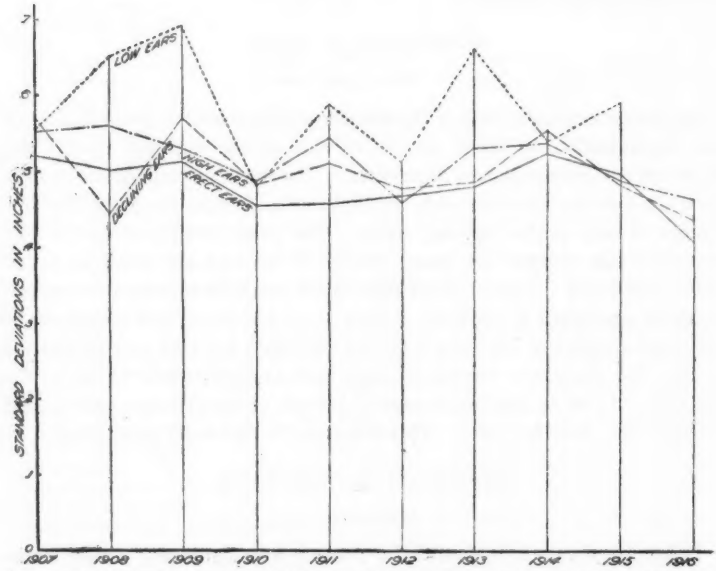

FIG. 22.—Graphs showing the standard deviation of the circumference of the ears of high- and low-ear strains of Indian corn.

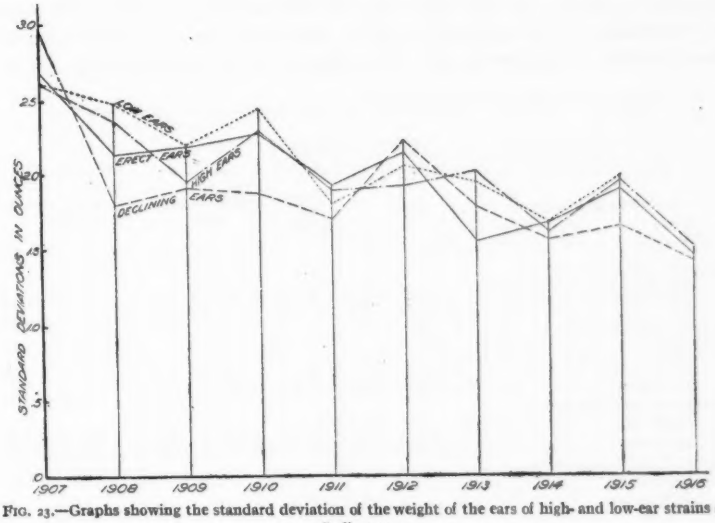

FIG. 23.—Graphs showing the standard deviation of the weight of the ears of high- and low-ear strains of Indian corn.

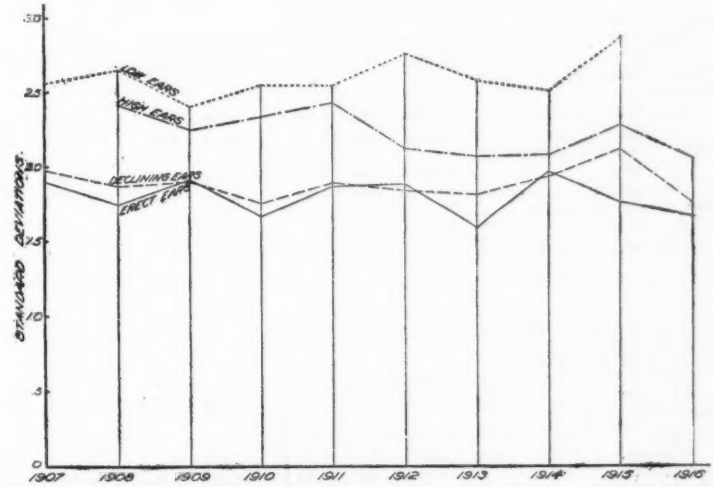

FIG. 24.—Graphs showing the standard deviation of the number of rows of kernels on the ears of high- and low-ear strains of Indian corn.

in variability between high and low ear strains. In the number of rows of kernels the standard deviation of the low-ear strain exceeds decidedly that of the high-ear strain in each season; but the coefficients of variability of the high-ear strain is sometimes greater and sometimes less than that of the low strain. The difference is probably not significant.

TABLE V.—*Type and variability of high- and low-ear strains of Indian corn*

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
CROP OF 1907				
Length of ear, in inches:				
High ears	7.459±0.033	8.0	1.128±0.023	15.12±0.32
Low ears	7.309± .033	7.5	1.139± .023	15.59± .34
Circumference of ear, in inches:				
High ears	6.645± .017	6.5	.551± .011	8.29± .18
Low ears	6.999± .017	7.0	.554± .011	7.93± .17
Weight of ear, in ounces:				
High ears	10.090± .081	10.0	2.608± .057	25.85± .59
Low ears	10.569± .079	12.0	2.613± .056	24.72± .57
Rows of kernels on ears:				
High ears				
Low ears	20.577± .083	20.0	2.559± .059	12.45± .29
CROP OF 1908				
Length of ear, in inches:				
High ears	6.380±0.039	6.5	1.251±0.027	19.61±0.45
Low ears	6.700± .035	6.5	1.148± .024	17.13± .38
Circumference of ear, in inches:				
High ears	6.148± .018	6.25	.560± .013	9.11± .21
Low ears	6.540± .020	6.5	.654± .014	10.00± .22
Weight of ear, in ounces:				
High ears	6.980± .080	6.0	2.358± .057	33.78± .89
Low ears	7.795± .080	9.0	2.477± .056	31.78± .79
Rows of kernels on ears:				
High ears	18.09 ± .091	18.0	2.424± .064	13.39± .37
Low ears	18.96 ± .088	18.0	2.650± .062	13.98± .33
CROP OF 1909				
Length of ear, in inches:				
High ears	6.128±0.030	6.5	1.042±0.022	16.76±0.35
Low ears	6.322± .027	6.5	1.032± .022	16.32± .36
Circumference of ear, in inches:				
High ears	5.942± .015	5.5	.529± .011	8.90± .18
Low ears	6.522± .021	6.25	.693± .015	10.62± .23
Weight of ear, in ounces:				
High ears	6.432± .057	7.0	1.952± .040	30.35± .69
Low ears	6.234± .070	6.0	2.204± .050	35.07± .88
Rows of kernels on ears:				
High ears	17.986± .076	18.0	2.258± .054	12.55± .31
Low ears	19.744± .097	20.0	2.410± .069	12.21± .35

TABLE V.—*Type and variability of high- and low-ear strains of Indian corn*—Continued

CROP OF 1910

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variability.
Length of ear, in inches:				
High ears	6.844±0.027	7.0	1.064±0.019	15.55±0.29
Low ears	7.152± .048	8.0	.978± .039	13.67± .24
Circumference of ear, in inches:				
High ears	6.543± .013	6.5	.487± .009	7.44± .14
Low ears	7.118± .012	7.0	.481± .008	6.76± .12
Weight of ear, in ounces:				
High ears	8.516± .060	9.0	2.281± .042	26.77± .53
Low ears	9.353± .061	10.0	2.435± .043	26.03± .49
Rows of kernels on ears:				
High ears	18.422± .065	18.0	2.342± .046	12.71± .25
Low ears	19.500± .067	20.0	2.546± .048	13.06± .25

CROP OF 1911

Length of ear, in inches:				
High ears	6.044±0.029	6.0	1.088±0.021	17.99±0.37
Low ears	5.991± .024	6.0	1.133± .017	18.91± .30
Circumference of ear, in inches:				
High ears	6.130± .015	6.25	.545± .011	8.89± .18
Low ears	6.317± .013	6.5	.588± .009	9.31± .15
Weight of ear, in ounces:				
High ears	6.488± .057	6.0	1.892± .041	29.16± .68
Low ears	5.913± .045	6.0	1.800± .032	30.44± .58
Rows of kernels on ears:				
High ears	17.308± .087	16.0	2.437± .062	14.08± .36
Low ears	18.510± .074	18.0	2.546± .053	13.75± .29

CROP OF 1912

Length of ear, in inches:				
High ears	6.898±0.031	7.5	1.035±0.022	15.00±0.33
Low ears	7.396± .029	7.5	1.052± .021	14.22± .29
Circumference of ear, in inches:				
High ears	6.202± .014	6.5	.459± .010	7.40± .16
Low ears	6.745± .014	6.75	.510± .010	7.56± .16
Weight of ear, in ounces:				
High ears	7.609± .062	7.0	1.919± .044	25.22± .61
Low ears	8.428± .060	9.0	2.055± .043	24.38± .55
Rows of kernels on ears:				
High ears	16.500± .071	16.0	2.130± .051	12.91± .32
Low ears	19.459± .083	18.0	2.766± .059	14.21± .31

TABLE V.—*Type and variability of high- and low-ear strains of Indian corn*—Continued

CROP OF 1913

Character and strain.	Mean.	Empirical mode.	Standard deviation.	Coefficient of variation.
Length of ear, in inches:				
High ears	6.107±0.037	6.5	1.157±0.026	18.95±0.44
Low ears	6.362± .032	6.5	1.172± .023	18.42± .37
Circumference of ear, in inches:				
High ears	5.895± .017	6.0	.529± .012	8.97± .21
Low ears	6.093± .017	6.0	.660± .012	10.83± .21
Weight of ear, in ounces:				
High ears	6.224± .068	6.0	2.008± .048	32.26± .84
Low ears	6.250± .057	6.0	1.942± .040	31.07± .69
Rows of kernels on ears:				
High ears	17.190± .076	16.0	2.080± .054	12.10 ± .32
Low ears	18.854± .089	18.0	2.576± .063	13.663± .34

CROP OF 1914

Length of ear, in inches:				
High ears	5.581±0.035	6.5	1.149±0.025	20.588±0.46
Low ears	6.410± .030	7.0	1.183± .022	18.456± .35
Circumference of ear, in inches:				
High ears	5.594± .017	5.75	.536± .012	9.582± .22
Low ears	5.992± .014	6.0	.540± .009	9.012± .17
Weight of ear, in ounces:				
High ears	5.491± .053	5.0	1.605± .038	29.230± .35
Low ears	6.105± .047	6.5	1.669± .033	27.338± .35
Rows of kernels on ears:				
High ears	16.350± .075	16.0	2.098± .053	12.832± .33
Low ears	18.992± .075	18.0	2.510± .053	13.216± .28

CROP OF 1915

Length of ear, in inches:				
High ears	6.693±0.034	6.5	1.137±0.024	16.990±0.37
Low ears	7.325± .032	8.0	1.151± .023	15.710± .33
Circumference of ear, in inches:				
High ears	5.963± .015	6.0	.486± .011	8.150± .18
Low ears	6.787± .017	6.75	.590± .012	8.690± .17
Weight of ear, in ounces:				
High ears	6.991± .063	8.0	1.946± .045	27.840± .69
Low ears	9.341± .065	10.0	2.178± .046	23.320± .53
Rows of kernels on ears:				
High ears	17.328± .072	16.0	2.280± .051	13.150± .30
Low ears	19.992± .084	20.0	2.874± .059	14.380± .30

CROP OF 1916[a]

Length of ear, in inches:				
High ears	5.399±0.039	5.5	1.147±0.028	21.24±0.54
Circumference of ear, in inches:				
High ears	5.178± .014	5.25	.465± .010	8.99± .20
Weight of ear, in ounces:				
High ears	4.221± .058	4.0	1.511± .041	35.79±1.09
Rows of kernels on ears:				
High ears	16.631± .090	16.0	2.075± .063	12.48± .39

[a] No data on low ears in 1916.

SUMMARY

THE FOUR STRAINS WITH RESPECT TO CHEMICAL COMPOSITION

(1) It is found that four distinct types of corn as regards length, circumference, weight of ears, and number of rows of kernels on ears are so well established that we may assign orders of values to the means of these characters that persist with but few exceptions in such changes of environment as have been experienced in 11 years of planting, from 1905 to 1915.

(2) While a few slight but significant progressive changes have been noted, the selections for chemical composition from 1905 to 1915 have not changed decidedly the differences in mean values of these characters. In fact, we are unable to assert with any high degree of probability that the strains differ more or less with respect to these characters during the second half of the period 1905 to 1915 than during the first half.

(3) The standard deviations of the strains do not differ nearly so much compared to their probable errors as do the means, and it is not in general nearly so easy to discriminate among strains by the differences of standard deviations as by the use of means. There is one marked exception to this, in that we easily distinguish high-protein and high-oil from low-protein and low-oil strains by the differences in the standard deviations in weights of ears.

(4) No progressive change of consequence has taken place in standard deviations.

(5) The coefficients of variability, in comparison to their probable errors, differ still less in a given season than the standard deviations, and there is no very general tendency for the coefficients of variability to maintain a definite order of values. That is to say, the differences of coefficients of variability of the four strains seem to be fairly well described, with certain exceptions noted in the paper, as random fluctuations.

TWO-EAR STRAINS

(6) The upper ears have a significantly larger mean value in length, weight, and circumference than have the lower ears on the same stalks.

(7) The means with respect to weight, length, and circumference of single ears are in each case larger than the corresponding means for the lower ears of the same plot. The means with respect to weight and circumference are also in general larger than these means for upper ears of the same plot. However, strange as it may appear, the mean lengths of single ears are on the whole less than those of upper ears.

(8) A striking fact in the comparison of the single ears with the upper and lower ears is the greater standard deviation in the weight of single ears.

ERECT- AND DECLINING-EAR STRAINS

(9) Taken as a whole, there are no significant differences in these two strains with respect to the characters considered. In view of the suggestion that ears are declining because of their greater weight, it is a fact of special interest that the declining ears are not on the whole heavier than erect ears.

HIGH- AND LOW-EAR STRAINS

(10) The ears of the low-ear strain are on the whole significantly larger in mean length, circumference, and weight than those of the high-ear strain, but there are a few exceptions. In each of the eight years considered the mean number of rows of kernels on ears is larger for the low-ear strain than for the high-ear strain.

(11) The standard deviation of number of rows of kernels in each year is distinctly greater for the low ears than for the high ears, and the standard deviation of circumstance of ears is in general larger for the low-ear strain than for the high-ear strain.

SOME NOTES ON THE DIRECT DETERMINATION OF THE HYGROSCOPIC COEFFICIENT [1]

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INTRODUCTION

The hygroscopic coefficient expresses the percentage of moisture contained in a soil which, in a dry condition, has been brought into a saturated atmosphere, kept at a constant temperature, and allowed to remain until approximate equilibrium with this atmosphere has been attained (12, p. x; 14, p. 76; 15, p. 196).[2] It has a twofold significance, both serving as a single-valued expression of the relative fineness of texture (12, p. xi), and, in soil-moisture studies, permitting the approximate estimation of the maximum amount of water available for growth and for the maintenance of life in the case of ordinary crop plants—the difference between the total amount of water and the hygroscopic coefficient (3, p. 121).

The error is sometimes made (20, p. 209) of confusing Mitscherlich's "*Hygroskopizität*" with the hygroscopic coefficient as above defined. The former is determined by allowing the exposed soils to come into equilibrium with an atmosphere in contact with a 10 per cent sulphuric-acid solution (24, p. 56) instead of with water, Mitscherlich holding that the determination by Hilgard's method gives results much too high on account of the condensation of moisture on the exposed samples (24, p. 156). The values obtained by his method are much lower than the hygroscopic coefficients, although either will serve to indicate the relative hygroscopicity and fineness of texture of the samples, as may also the much simpler determination of the hygroscopic moisture contained in air-dried soils exposed freely side by side to the air of an ordinary room for some time (4, p. 351), or that of the moisture equivalent (7, p. 140).

The term "hygroscopic coefficient" was introduced by Hilgard in 1874 (13, p. 9), but as early as 1859 he had developed the method for its determination which he continued to use for more than 50 years, referring to the value, previous to the date mentioned, as the hygroscopic moist-

[1] The work reported in this paper was carried out in 1910 to 1913 at the Nebraska Agricultural Experiment Station, where the authors were, respectively, Chemist, Assistant in Chemistry, and Research Assistant in Chemistry.

[2] Reference is made by number to "Literature cited," p. 165-166.

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ure absorbed at $x°$ C., x being the temperature at which the absorption boxes had been exposed. The conception of making such a determination did not originate with Hilgard, but with Schübler as early as 1830. The method (27, p. 80) of the latter, however, did not insure the absorption of the maximum amount of moisture, too thick a layer of soil being exposed. Hilgard's method is a refinement of that of Schübler, providing for a higher humidity of the atmosphere, a shallower layer of soil, thus permitting a more rapid saturation, and lastly the avoidance of fluctuations in temperature, which cause a precipitation of dew upon the soil.

The hygroscopic coefficient of soils has been but rarely determined during the past 40 years, although during the previous four or five decades it had received considerable recognition. In the early days of soil investigation undue importance was attached to the relative absorbent powers of soils with respect to atmospheric moisture, it being supposed that it served to some extent as an index of fertility. Thus, Davy (9, p. 184) states:

> I have compared the absorbent power of many soils with respect to atmospheric moisture, and I have always found it greatest in the most fertile soils; so that it affords one method of judging of the productiveness of land.

He also considered that in the case of soils with a high hygroscopic coefficient plants were supplied with moisture in periods of drouth, the hygroscopic power of the soil enabling it to render the water of the atmosphere available to the plants (9, p. 183). Schübler accepted the second of Davy's views but not the first, mentioning (27, p. 82) that he had found that a

> pure, infertile clay absorbs in 12 hours . . . more than the very fertile garden soil.—Translation.

Liebig (17. p. 48) also accepted Davy's view as to the value of the moisture absorbed from the air, and it continued to be indorsed by the foremost investigators until 1875, when the work of Sachs, Wilhelm, Reisler, Heinrich, and Mayer finally proved the falsity of it. The reaction from the old view carried to the opposite extreme, and it became almost universally accepted that a knowledge of the hygroscopic power of different soils is practically valueless. Apparently the question of the usefulness of a knowledge of the relative hygroscopicity of a soil was confused with the distinct question of the usefulness to plants of the hygroscopic moisture. Mayer appears largely responsible for this confusion. In 1871 (21, p. 130) he fully indorsed the older view:

> The absorptive power of the soil for water . . . is under all circumstances a *useful soil property*, as it becomes active only when there is an actual scarcity of water in the soil and so acts as a regulator . . . The water thus condensed in porous solid bodies conducts itself exactly like other capillary held water and can, for example, when a field soil has in this way condensed water, be taken up by a plant's roots just like that

which has entered the small interstices of the soil from the rain or by watering.—Translation.

Four years later, having completed his proof of the falsity of this view, he strongly discouraged determining the hygroscopicity of soils on the ground that it would cause confusion if very hygroscopic soils were indicated as retentive of an especially high percentage of water in a non-available form, when this was not an actual disadvantage, for the reason that the most hygroscopic soils were the very ones that were able to hold the largest amounts of total water (22, p. 248):

> By a remarkable coincidence the most strongly condensing soils usually are those with the highest water capacity and it would probably only cause confusion if we were to mark these soils with a blemish in regard to the supply of water on account of a not very productive correction.—Translation.

However, he still clearly recognized that the amount of water remaining in a soil on the wilting of a plant was closely related to the maximum amount of moisture which the soil was able to absorb from a nearly saturated atmosphere.

During the last quarter of the nineteenth century Hilgard and Loughridge appear to have been the only investigators who continued to attach any importance to the determination of the hygroscopic coefficient in connection with soil-moisture studies. The general attitude of soil investigators during that period is well illustrated by the numerous publications of one of the foremost, the late Dr. F. H. King, in which the determination, the importance, and the use of the hygroscopic coefficient are ignored.

At the beginning of the present century Mitscherlich began to call attention to the importance of the relative hygroscopicity of soils (23) to which he attached extreme importance. In Europe the importance of a knowledge of the hygroscopicity of soils is still practically ignored except by Mitscherlich and by Hall (11, p. 84–88).

Naturally, under such circumstances, the particular method developed by Hilgard received little critical consideration. It appears that no one except himself had investigated the method with the object of determining the experimental errors involved, previous to our beginning the use of it on an extensive scale for the interpretation of field-moisture data. We had originally no intention of studying the method itself, and our observations have resulted from difficulties encountered in its use, part of them due to attempts to expedite the determination without lessening its accuracy.

Lipman and Sharp (18), while associated with Hilgard, studied the effect of a rise or fall of the temperature and also of the thickness of the exposed layer of soil upon the amount of hygroscopic moisture absorbed.

Briggs and Shantz (8, p. 64) studying the relationship between the moisture equivalent and the hygroscopic coefficient found that the deter-

mination of the latter "unless carried out with special precautions, is not very exact."

HILGARD'S METHOD

Details of this were published earliest by Loughridge (19), who had been a student under Hilgard at the University of Mississippi. Later (14, p. 76) it was described by the latter as follows:

> The fine earth is exposed to an atmosphere saturated with moisture for about twelve hours at the ordinary temperature (60° F.) of the cellar in which the box should be kept. For this it is sifted in a layer of about 1 mm. thickness upon glazed paper, on a wooden table in a small water-tight covered box (12 by 9 by 8 inches) in which there is about an inch of water; the interior sides and cover of the box should be lined with blotting paper, kept saturated with water, to insure the saturation of the air. . . .
>
> After eight to twelve hours the earth is transferred as quickly as possible, in the cellar, to a weighed drying-tube and weighed. The tube is then placed in a paraffin bath, the temperature gradually raised to 200° C. and kept there 20 to 30 minutes (rapidity of raising temperature depending upon the amount of moisture in the soil), a current of dry air passing continually through the tube. It is then weighed again, and the loss in weight gives the hygroscopic moisture in saturated air.

Some time later, to avoid the decomposition of the organic matter of surface soils, Hilgard modified the method to the extent of using an air bath, raising the temperature to only 110° C, keeping the sample in for an hour, weighing, drying again, and continuing the process until a practically constant weight was obtained.[1]

Under "fine earth" was included the material finer than 0.5 mm. resulting from the sample being reduced by a rubber pestle, instead of by one of steel or porcelain, to prevent any crushing of soil particles. He sometimes digested clayey soils with distilled water until fully disintegrated, after which the muddy water was evaporated with the soil slush and the whole thoroughly mixed. As the determination of the hygroscopic coefficient was, with Hilgard, almost always incidental to a chemical or physical analysis of the soil, this rather tedious preliminary preparation of the sample was no serious matter in view of the great amount of time and labor involved in the detailed analyses to follow.

Hilgard studied the effect of differences in temperature upon the amount of moisture absorbed by a soil and found that it increased with the temperature, provided that the saturation of the air was maintained. In this view he was not confirmed by the work of Knop (16), Schlœsing (26), Ammon (6), and Von Dobeneck (10), who found a lower absorption at higher temperatures. He attributed their findings to their failure to provide for the saturation of the air inclosed within the absorption vessel.

More recently Patten and Gallagher (25, p. 31–35) have reported some data confirming the view of Knop, etc., but, as Lipman and Sharp have pointed out (18, p. 716), their description of their methods makes it evident

[1] HILGARD, E. W. METHODS OF PHYSICAL AND CHEMICAL SOIL ANALYSIS. Cal. Agr. Exp. Sta. Circ. 6, p. 17. 1903.

that the conditions of their experiments were not such as to insure that the exposed soils became saturated with hygroscopic moisture. The work of Patten and Gallagher (25), confirming that of the earlier investigators mentioned, has unfortunately had the effect of leading to the generally accepted view that, in his conclusions, Hilgard was in error (20, p. 367).

WORK OF LIPMAN AND SHARP

As a reply to the criticisms of Patten and Gallagher, Lipman and Sharp (18) report a study of the effect of the thickness of the layer of exposed soil and of the temperature of exposure, using boxes 12 by 18 by 19 inches, similar to those employed by Hilgard in his later work (15, p. 198), but longer and wider than those mentioned in the above quotation (14, p. 76). They also used glazed paper placed on wooden tables with the tops only 1 inch above the surface of the water. They compared three depths (1.5, 4, and 8.5 mm.) of an adobe soil exposed for various intervals, ranging from 1.5 to 455 hours, and at temperatures from 12° to 34.75 °C. With two other soils the periods of exposure were quite similar, but the range in temperature was less, while the thickness of the soil layer did not exceed 2 mm.

Lipman and Sharp found in general that a greater amount of moisture was absorbed at the higher temperatures, and emphasize the necessity of using very thin layers of soil, having found about 1 mm. the best. They conclude that 8 to 10 hours' exposure of air-dried soils is sufficient when the depth of the layer is only 1 mm. and the boxes are of the dimensions they used. They call attention to the difficulty of securing the saturation of the air at any considerable distance from the water surface.

These authors mention that duplicate samples agreed remarkably well. However, if they were run side by side, this agreement, as pointed out below, does not serve as evidence of the accuracy of the determination.

EXPERIMENTAL WORK

Two of us had previously (1, p. 590; 2; 5, p. 277–281) employed the method on a very limited scale, using an improvised place for the absorption boxes. We found the loose sheets of glazed paper so inconvenient that we introduced a modification that greatly facilitated the work, substituting light pasteboard trays 7 inches long, 5 inches wide, and 0.75 inch high, lined with glazed paper. On starting the determinations at the University of Nebraska we again used this modification, having had a large supply of the pasteboard trays lined with the glazed paper manufactured by a local box company. As these one by one became somewhat limp from exposure to the damp atmosphere maintained in the absorption boxes, they were discarded and new ones substituted.

We used wooden boxes of the dimensions given by Hilgard, lining both the boxes and the covers with blotting paper as specified. To prevent the warping of the sides and cover, it was found desirable first thoroughly

to paraffin these. To prevent leakage of water a galvanized-iron tray, 3 to 4 inches high and made to fit snugly, was placed in the bottom of the wooden box, the blotting paper extending from the top of the sides of the wooden box to the bottom of the metal tray. By means of metal supports a wooden table was held in position 1 to 2 inches above the surface of the water and from 0.5 to 1 inch from each paper-lined side of the box. In the later determinations a table of galvanized-wire screen was substituted, as it occupied less space.

To provide a constant temperature room, we inclosed with alternate layers of building paper and boards a portion of the cellar of the Experiment Station building that was windowless and not in contact with any outside wall. An electric light on the outside of a double window furnished the necessary illumination without heating the room. The operator opened and closed the door as quickly as possible on entering the room daily to change the soil in the trays. A maximum and minimum thermometer was hung in the room, and the daily readings were recorded. Later a recording hygrometer was added. No sudden changes in temperature or humidity were observed.

We employed 24 absorption boxes, which were placed on low shelves against the heavy inside brick wall. From the first we had exposed samples of two control soils in different absorption boxes. At first the object of this was to find the variation in the coefficient of the same soil from day to day, but later to indicate whether any abnormal conditions had prevailed in the room, the boxes, or the drying oven. Of the two control soils used on the same day the one was a subsoil with a coefficient of about 5 to 6, while the other was a finer-textured soil or subsoil with a coefficient between 10 and 22. The two control soils were exposed, each in duplicate, from day to day along with a large number of the samples under investigation, the latter also being in duplicate. The time of exposure varied from 15 to 16 hours, the boxes being filled at 4 or 5 o'clock in the afternoon and opened shortly after 8 o'clock on the following morning. The results both with the duplicates exposed on the same day and with the controls from day to day were so concordant that the method was accepted as reliable, and some 2,000 determinations were thus made. We did not suspect the unreliability of the results until, through force of circumstances, one set had to be left in the boxes for 48 hours. On drying these samples it was found that the two control soils had absorbed much more moisture than on any previous occasion. We then investigated the cause of this and finally discarded all the data and made new determinations. It was while trying to devise such modifications of the method described by Hilgard as would permit the large number of determinations in connection with our field moisture studies being made as rapidly as possible without lessening the accuracy that we secured the data reported below on the influence of the material of the trays, the effect of the temperature, previous drying, etc.

RAPID LOSS OF HYGROSCOPIC MOISTURE

When soils carrying the maximum amount of hygroscopic moisture—that is, an amount equal to the hygroscopic coefficient—are exposed to an ordinarily dry air, they lose water at first as rapidly as though placed in a desiccator containing sulphuric acid. This makes it important that the transfer of the exposed soil from the trays to the weighing bottles should be made as rapidly as possible.

Fifty-gm. portions of two soils, A and B, which had previously been exposed in hygroscopic boxes until the moisture content was approximately equal to the hygroscopic coefficient were placed in each of 10 weighing bottles. The depth of soil was about 5 cm. Five bottles of each were placed in a desiccator containing concentrated sulphuric acid, while the other five were exposed on a shelf in the laboratory. All were weighed at intervals until those of the latter set ceased to lose weight, four weeks being necessary. Those in the desiccators were exposed nearly five months longer, and at the end of this time they were almost oven-dry. The changes in the case of the individual members of each of the four sets were so similar that only the averages need be reported (Table I). In a similar desiccator containing sulphuric acid and in weighing bottles of the same kind we exposed distilled water. The loss of water between February 12 and March 19 amounted to about 45 gm., or 90 per cent of the weight of soil A contained in similar weighing bottles.

TABLE I.—*Percentage of water in 50-gm. portions of soils exposed to the air of the laboratory compared with that in a desiccator with sulphuric acid*

Date.	Soil A.		Soil B.	
	Exposed to air.	In desiccator.	Exposed to air.	In desiccator.
Feb. 12	5.26	5.26	11.00	11.00
18	2.27	2.45	6.18	6.70
26	1.60	1.30	4.07	4.04
Mar. 5	1.79	.96	4.09	2.95
19	1.82	.61	4.17	1.91
Apr. 1	.....	.44	.....	1.49
8	.....	.40	.....	1.35
May 21	.....	.25	.....	.88
Aug. 10	.....	.12	.....	.43

At the end of two weeks both soils appeared to have reached equilibrium with the air of the laboratory.

In the case of the absorption boxes and trays, an operator, after a little practice, will be able to open a box, transfer the samples from the two trays to weighing bottles, and stopper these within the space of 30 seconds.

In the case of each of three soils, we exposed two trays of the soil in each of three absorption boxes. From each box we transferred one sample to a weighing bottle as quickly as possible, this requiring from 23 to 30 seconds. The other was transferred from a tray to a weighing bottle and back again three times, so as to consume 150 seconds in the operation. With each soil an appreciable loss of moisture is observable (Table II), but this is so small and the time purposely consumed in the one case so much longer than would be needed by any operator that it appears that no serious error from this source need be feared if the operator simply makes the transfer as speedily as he can.

TABLE II.—*Influence of speed of transfer of soil from tray to weighing bottle upon amount of hygroscopic moisture found*

Soil.	Hygroscopic moisture.	
	Transferred once, requiring 20 to 30 seconds.	Transferred three times, consuming 150 seconds.
C	0.5	0.3
D	4.8	4.2
E	18.7	16.6

SUITABILITY OF TRAYS OF VARIOUS MATERIALS

Using four control soils, A, C, F, and G, we compared trays of aluminum, copper, zinc, tin plate, glass, vulcanized rubber, granite ware, and those of pasteboard described above. Part of the last had been saturated with paraffin before being lined with glazed paper. In some, paraffined pasteboard formed the sides, but the bottom was cut out, thus making a portion of the glazed paper lining the bottom of the tray. The metal trays were 7 inches long, 5 inches wide, and 0.75 inch deep. The trays of glass, granite ware, and vulcanized rubber were photographers' trays, having almost the same dimensions as the preceding. To distribute the thin layer of dry soil in the trays, an aluminum salt shaker was found very convenient.

In order to determine the approximate maximum amount of moisture that was likely to condense on the layers of soil independent of its internal surface, we exposed coarse quartz sand of 0.5 to 1 mm. diameter in duplicate in all the different kinds of trays, both for 16- and for 38-hour periods. The amount of absorbed moisture was independent of both the kind of tray and the time of exposure, varying from 0.02 to 0.14 per cent, with an average of 0.06, an amount quite negligible in connection with soil-moisture studies.

TABLE III.—*Comparison of trays of different materials in the determination of the hygroscopic coefficient*

Material of tray.	Hygroscopic coefficients found after—				
	24 hours' exposure.				48 hours' exposure.
	Soil C.	Soil A.	Soil F.	Soil G.	Soil G.
Pasteboard lined with glazed paper	0.6	4.5	.....	15.5	16.6
Paraffined pasteboard lined with glazed paper	.7	5.1	.....	18.2	17.4
Paraffined pasteboard sides, but no bottom, lined with glazed paper	.....	5.4	.....	20.3	.....
Glass	.6	5.6	.....	19.4	19.2
Vulcanized rubber	.6	5.7	17.7	.....	.....
Graniteware	.6	5.4	17.9	.....	.....
Tin plate	.6	5.6	.....	.....	.....
Zinc	.5	5.7	17.9	20.0	19.7
Copper	.7	5.5	17.7	19.2	18.9
Aluminum	.7	5.6	17.7	19.5	19.9

The data reported in Table III show that any of the materials mentioned, except the pasteboard, may safely be used. Even the trays with paraffined pasteboard sides, but with only a glazed paper bottom, appear allowable. The low amount of moisture absorbed by the soils when placed on glazed paper in the pasteboard trays with pasteboard bottoms is probably due to the competition of the pasteboard, which, itself, is hygroscopic and absorbs moisture from a saturated atmosphere. The somewhat low results obtained with the glazed paper used in paraffined pasteboard trays may be due to the competition of the lower unglazed surface of the glazed paper, which, when placed directly upon the table in the absorption box is able to absorb moisture from the air reaching it from below.

That the saturation with hygroscopic moisture is practically complete at the end of 24 hours with all the trays except those of pasteboard is to be seen from the failure of the soil G to absorb additional moisture during the second 24 hours. All the samples of this soil were placed in the hygroscopic boxes at the same time, but part were removed at the end of the first 24 hours. During the first day the temperature in the hygroscopic room fell from 17° to 16° C. and during the next day from 16° to 14° C.

The trays of tin plate readily rusted, and those of zinc soon corroded to such an extent that the soil adhered. On the whole, those of aluminum or copper were found the most satisfactory, and in our later work we used trays made of the former metal, with the dimensions given above.

INFLUENCE OF TIME OF EXPOSURE

In handling a large number of absorption boxes 8 hours' actual exposure necessitates a working day in the laboratory of about 10 hours, on account of the additional time required in the morning to place the samples in the trays and in the afternoon to transfer them to weighing bottles. Twelve hours, the maximum exposure used by Hilgard, also is inconvenient, as usually it will necessitate an extra trip to the laboratory. We tried various intervals. The soils exposed on the metal trays, unlike those on the glazed paper used by Hilgard, in most cases continued to gain in weight during the first 18 hours, thus rendering both the 8- and 12- hour exposures too brief. As, under our conditions, from 22 to 24 hours was the most convenient interval, we compared this with longer exposures. Except in the case of very fine textured soils like I, after the first 20 hours there was generally no important increase in weight (Table IV). As under our working conditions it was not possible to maintain the temperature constant during long periods, this increase with such very hygroscopic soils may have been caused by dew formation resulting from a depression of the temperature after the atmosphere had become saturated. In some prolonged exposures there was a slight decrease in weight during the later portion of the period.

TABLE IV.—*Influence of the length of the time of exposure upon the amount of moisture absorbed*

Experiment No.	Time of exposure in hygroscopic boxes.	Temperature.	Absorbed moisture.		
			Soil H.	Soil G.	Soil I.
		°C.	*Per cent.*	*Per cent.*	*Per cent.*
1	23 hours	18.5	6.3	.....	.....
2	23 hours	19.0	6.0	.....	.....
3	41 hours	18.0	5.8	.....	.....
4	5 days	18.5	6.4	.....	.....
5	6 days	19.0	6.9	.....	.....
6	7 days	19.0	6.8	.....	.....
7	11 days	19.0	6.6	.....	.....
8	25 hours	18.0	.....	.....	21.3
9	4 days	17.0	.....	.....	23.1
10	24 hours	17.0	.....	19.5	.....
11	48 hours	17.0	.....	19.4	.....

INFLUENCE OF TEMPERATURE

The variation in the temperature of the room in which the absorption boxes were kept was so little that from April 27 to October 1, 1911, the thermometer readings lay between 22° and 24° C. so much of the time that the data from days with either lower or higher temperatures are too few to be of service in the present connection. The same applies to the interval extending from January 4 to April 22, 1913, when the temperatures on nearly every day were between 17° and 20° C.

In the case of one of the control soils, I, the values shown in Table V were obtained by 24 hours' exposure at different temperatures. Another control soil, A, was used in both summer and winter. Higher values (Table VI) were found during the warmer weather. When any distinct change was caused by an elevation of the temperature, it appeared in all cases to be an increase rather than a decrease in the amount of moisture absorbed. This is in accordance with the conclusions of Hilgard and of Lipman and Sharp.

TABLE V.—*Influence of the temperature upon the amount of moisture absorbed by Soil I*

Date.	Temperature.		Hygroscopic coefficient.				
	Maximum.	Minimum.	Determination 1.	Determination 2.	Determination 3.	Determination 4.	Average.
	°C.	°C.					
Jan. 17–18	21. 5	21	24. 0	22. 3	24. 7	25. 3	24. 1
Feb. 27–28	16. 0	15	20. 7	20. 4	20. 2	.....	20. 4
Feb. 29–Mar. 1	14. 5	12	19. 7	19. 6	....	.....	19. 6

TABLE VI.—*Concordance of values found on successive days for the hygroscopic coefficients of control soils*

Date.	Temperature of room.		Soil A.			Soil B.		
			Determination.			Determination.		
	Maximum.	Minimum.	1	2	Average.	1	2	Average.
	°C.	°C.						
Jan. 22	16	15	5. 6	6. 0	5. 8	10. 2	10. 0	10. 1
23	16	15	5. 9	5. 9	5. 9	10. 5	10. 0	10. 2
24	17	17	5. 7	5. 7	5. 7	10. 2	10. 0	10. 1
25	18	18	5. 5	5. 5	5. 5	10. 4	10. 0	10. 2
26	19	18	5. 5	5. 6	5. 5	10. 0	10. 0	10. 0
27	21	16	5. 6	5. 6	5. 6	9. 9	9. 9	9. 9
28	21	16	5. 6	5. 8	5. 7	10. 2	.....	10. 2
29	20	16	5. 5	5. 5	5. 5	10. 0	10. 0	10. 0
Feb. 2	20	16	5. 5	5. 6	5. 5	10. 1	10. 0	10. 0
4	17	15	5. 9	6. 1	6. 0	10. 2	10. 4	10. 3
Average	.....	.....	.....	.....	5. 7	.....	.....	10. 1
			Soil A.			Soil I.		
June 12	22	22	5. 9	5. 4	5. 6	20. 0	20. 1	20. 0
13	22	21	5. 7	5. 9	5. 8	20. 0	20. 0	20. 0
14	23	23	6. 3	6. 1	6. 2	21. 6	21. 6	21. 6
15	23	22	6. 0	6. 4	6. 2	22. 9	22. 3	22. 6
16	23	22	6. 2	6. 3	6. 2	22. 0	22. 5	22. 2
17	23	22	6. 0	6. 3	6. 1	23. 0	23. 0	23. 0
19	22	22	6. 0	5. 8	5. 9	22. 0	22. 1	22. 0
20	23	22	6. 2	6. 1	6. 1	20. 4	20. 9	20. 5
21	23	22	6. 4	.....	6. 4	22. 0	22. 6	22. 3
23	23	23	6. 4	.....	6. 4	20. 0	21. 4	20. 7
Average	.....	.....	.....	.....	6. 1	.....	.....	21. 5

EFFECT OF GREAT FLUCTUATIONS IN THE TEMPERATURE OF THE ROOM

To obtain some idea as to how great a fluctuation in temperature is permissible we exposed soil F for 17 hours simultaneously in a laboratory and in a greenhouse as well as in the basement room used regularly for such work. In the plant house where the range of temperature was greatest the amount of moisture absorbed (Table VII) was the highest. In the laboratory where the temperature was much higher during the day than during the night the amount of moisture absorbed was lower than in the constant temperature room.

TABLE VII.—*Influence of variations in the temperature of the room of exposure upon the amount of moisture absorbed*

Determination.	Hygroscopic coefficient.		
	In constant temperature room (11° to 11° C.).	In laboratory (9° to 16° C.).	In plant house (23° to 29° C.).
1	17.4	16.5	19.7
2	17.0	16.5	20.1

EFFECT OF OVEN DRYING

In field moisture studies it is usually much more convenient to determine the total moisture content of the sample and then to use a portion of this dried material for the determination of the hygroscopic coefficient than to air dry a portion of the original sample. If the previous drying should appreciably alter the value of the coefficient, it would become necessary to air dry a separate portion of the sample.

With four subsoils (Table VIII) we determined the coefficient, using the air-dried form of each. as well as portions dried at 100°, 110°, 150°, and 175° C.

TABLE VIII.—*Effect of drying soils at different temperatures previous to their exposure in the absorption boxes*

Soil.	Hygroscopic coefficient.				
	Air-dried.	Dried at 100° C.	Dried at 110° C.	Dried at 150° C.	Dried at 175° C.
A	0.7	.....	.....	0.7	0.7
C	5.6	5.3	5.2	5.2	5.4
J	12.0	11.6	11.7	12.1	.....
I	22.3	.....	.....	21.3	20.8

The above would indicate that in the case of a mineral subsoil a temperature as high as 175° C. may be permissible. If the subsoil should be one containing any considerable amount of organic matter, such a temperature should not be employed, but one of 105° to 110° C. we found to have no distinct influence upon the values found for silt-loam surface soils containing 2 per cent of organic carbon. We made no experiments with peat soils or with mineral soils very rich in organic matter.

EFFECT OF GRINDING

As many fine-textured samples when first removed from the drying oven are so bricklike that it is difficult to reduce them with a rubber pestle so that they will pass a 1-mm. sieve it is desirable to know whether the hygroscopicity is appreciably increased by freely grinding them in a steel mortar until they will pass through such a sieve. The samples we used were four control soils, three of which, unless they had first been moistened and then oven-dried, needed no grinding to pass a 1-mm. sieve, while the fourth did not need it even then. A portion of each was ground in a steel mortar until it passed through a silk bolting cloth with openings of 0.25 mm. (Table IX).

TABLE IX.—*Influence of grinding upon the amount of moisture absorbed*

Soil.	Hygroscopic coefficient.	
	Unground (2–1 mm.).	Finely ground (below 0.25 mm.).
C	0.8	1.4
A	5.8	5.7
B	10.9	10.5
I	22.0	21.7

Only in the case of the very coarse-textured soil, C, which in practice would not need grinding, did we find any increase in the hygroscopicity. If a ball mill were employed, the reduction in size of particles might easily be so great as to affect seriously the value found.

It would appear that the dried samples, if very hard, may safely be reduced in a steel mortar until they pass a 1-mm. sieve.

INFLUENCE OF SIZE OF ABSORPTION BOXES AND THE NUMBER OF TABLES

With two soils, H and S, larger absorption boxes were also tried, these being lined with blotting paper as with the smaller ones. We used one 23.25 inches long, 16 inches wide, and 6.25 inches high, and another 12 inches square and 30 inches high, these being the inside dimensions. In the first an exposure of about 72 hours was necessary to bring the

absorbed moisture to as high a point as was found in the smaller boxes at the end of 24 hours, while in the second even this was not a sufficiently long exposure.

In the small absorption boxes we also tried using two tables, one placed 1 to 2 inches above the surface of the water and the other 2 inches still higher. In this manner four trays, two on each table, could be placed in a single absorption box. In all cases the results were unsatisfactory, the soil in the trays on the lower table absorbing less moisture than those on the upper.

CONCORDANCE OF DETERMINATIONS IN PRACTICE

An illustration of the variation in the values found for a particular soil from day to day is afforded by a series of 30 samples of loess soils used in cylinder experiments (3, p. 78–115). On four consecutive days a single determination was made on each (Table X), using as controls two soils, H and K, with coefficients of 6.1 and 14.2, respectively. Three trays with the former and two with the latter were exposed each day. It will be observed that the values obtained for the different samples rose and fell together day by day and that the control soils indicate both the direction and in general the magnitude of this fluctuation. Both controls showed the highest values on the second day and the next highest on the first, while on both the third and the fourth they were slightly lower than on either of the previous days. Of the 30 other soils 28 showed the highest values on the second day, 25 the next highest on the first, while 22 were third highest on the third day, and 14 on the fourth day. As the values obtained for the controls on the last two days were nearest those commonly found, we used the averages of the values found on these two days for the 30 other soils in estimating the amount of free water (3, p. 97).

TABLE X.—*Concordance of determinations of the hygroscopic coefficient on successive days*

Source (Nebraska).	Depth.	Hygroscopic coefficient.				
		1st day.	2d day.	3d day.	4th day.	Average.
	Feet.					
Wauneta	1	10.0	10.3	9.4	9.0	9.6
Do	2	10.4	10.7	9.5	9.5	10.0
Do	3	10.3	10.9	10.0	9.7	10.2
Do	4	10.3	10.7	10.2	10.0	10.3
Do	5	9.7	10.2	9.5	9.4	9.7
Do	6	8.7	9.0	8.8	8.5	8.7
McCook	1	9.7	10.5	9.5	9.3	9.7
Do	2	11.0	11.9	11.1	10.8	11.2
Do	3	10.1	10.9	9.8	9.5	10.1
Do	4	9.4	9.6	9.0	9.0	9.2
Do	5	9.4	9.6	8.8	8.7	9.1
Do	6	9.4	9.3	8.6	8.2	8.8
Holdrege	1	10.7	11.5	10.0	10.3	10.6
Do	2	12.2	13.2	11.7	11.7	12.2
Do	3	12.2	13.8	12.0	11.9	12.5
Do	4	11.1	12.0	10.6	10.6	11.0
Do	5	10.0	11.1	9.8	9.6	10.1
Do	6	10.0	10.8	9.5	9.6	9.9
Hastings	1	11.1	12.0	11.0	10.4	11.1
Do	2	13.7	15.0	13.2	13.2	13.7
Do	3	12.5	13.0	12.0	11.5	12.2
Do	4	11.6	12.9	11.6	11.5	11.9
Do	5	10.7	11.9	10.7	11.0	11.1
Do	6	10.9	11.7	10.3	10.7	10.9
Lincoln	1	12.3	12.7	12.3	12.0	12.3
Do	2	15.5	16.6	15.3	15.3	15.7
Do	3	15.3	16.0	14.6	14.6	15.1
Do	4	15.2	15.1	13.2	13.3	14.2
Do	5	14.5	14.7	13.1	13.2	13.8
Do	6	15.0	15.2	13.6	13.5	14.3
Control H, determination 1	.....	6.7	7.1	6.1	6.3	.....
Control H, determination 2	.....	6.2	6.7	6.2	6.0	.....
Control H, determination 3	.....	6.3	6.7	6.1	6.0	.....
Control K, determination 1	.....	14.5	15.0	14.2	14.3	.....
Control K, determination 2	.....	14.8	15.0	14.0	14.2	.....
Maximum temperature °C	.....	23	24	22	23	.....
Minimum temperature °C	.....	22	23	22	22	.....

TABLE XI.—*Concordance of single determination of the hygroscopic coefficient made on different days with the average of 10 previous determinations*[a]

Source (Nebraska).	Depth.	Hygroscopic coefficient.				Departure of individual determinations from average of 10 previous determinations.		
		Average of 10 previous determinations.	Individual determination.					
			1st day.	2d day.	3d day.	Det. 1.	Det. 2.	Det. 3.
	Feet.							
Wauneta	1	9.1	10.1	8.6	9.2	1.0	−0.5	0.1
Do	2	9.6	10.2	9.1	9.3	.6	−.5	−.3
Do	3	9.7	10.5	9.4	9.2	.8	−.3	−.5
Do	4	9.9	10.2	9.1	9.2	.3	−.8	−.7
Do	5	9.0	10.0	8.5	8.2	1.0	−.5	−.8
Do	6	8.3	8.3	8.1	7.8	0.0	−.2	−.5
McCook	1	10.0	10.4	9.8	9.5	0.4	−.2	−.5
Do	2	10.9	9.6	11.0	10.0	−.3	−.1	−.9
Do	3	10.7	11.1	9.9	9.9	.4	−.8	−.8
Do	4	9.7	10.3	9.9	9.0	.6	.2	−.7
Do	5	9.1	9.2	8.7	8.6	.1	−.4	−.5
Do	6	9.1	9.3	8.5	8.7	.2	−.6	−.4
Holdrege	1	10.1	10.9	11.0	*8.0*	.8	.9	*−2.1*
Do	2	11.2	11.1	12.0	11.9	−.1	.8	0.7
Do	3	11.3	11.0	12.0	*14.0*	−.3	.7	*2.7*
Do	4	10.2	11.1	10.5	10.3	.9	.3	.1
Do	5	9.6	10.3	9.6	9.6	.7	.0	.0
Do	6	9.4	10.3	9.4	8.3	.9	.0	−1.1
Hastings	1	9.6	10.2	10.3	9.6	.6	.7	.0
Do	2	11.6	12.6	12.8	12.9	1.0	1.2	1.3
Do	3	12.4	13.3	13.2	11.5	0.9	.8	−0.9
Do	4	11.1	12.3	11.8	11.2	1.3	.7	.1
Do	5	10.7	11.5	11.1	10.8	0.8	.4	.1
Do	6	10.7	11.6	10.7	10.5	.9	.0	−.2
Lincoln	1	12.0	12.3	12.5	12.2	.3	.5	.2
Do	2	14.4	14.8	14.4	14.0	.4	.0	−.4
Do	3	13.6	*16.2*	14.5	13.7	*2.6*	.9	.1
Do	4	13.0	13.6	13.5	13.8	.6	.5	.8
Do	5	12.8	13.5	12.9	12.7	.7	.1	.1
Do	6	12.7	12.7	12.5	12.0	.0	−.2	−.7
Weeping Water	1	12.1	12.5	12.3	12.1	.4	.2	.0
Do	2	13.7	14.5	*10.8*	13.4	.8	*−2.9*	−.3
Do	3	13.9	14.3	14.3	13.4	.4	.4	−.5
Do	4	13.0	13.6	13.5	12.5	.6	.5	−.5
Do	5	12.6	13.2	13.1	12.1	.6	.5	−.5
Do	6	12.5	13.0	12.6	11.9	.5	.1	−.6
Control A, Determination 1	.....	.....	5.8	5.5	5.5	.....	.....	.....
Control A, Determination 2	.....	.....	5.9	5.7	5.5	.....	.....	.....
Control A, Determination 3	.....	.....	5.8	5.7	5.4	.....	.....	.....
Control A, average	.....	5.6	5.8	5.7	5.5	.2	.1	.0
Maximum temperature...°C.	.....	.....	19	10	19	.....	.....	.....
Minimum temperature...°C.	.....	.....	17	18	16	.....	.....	.....

[a] The data in italics would in practice be rejected, but serve to illustrate the importance of duplicate determinations.

Another illustration is afforded by the data in Table XI on distinct sets of samples taken from the same localities as those appearing in the preceding table.

In the case of 30 sets, each consisting of 6 samples, hygroscopic-coefficient determinations had been made in duplicate on each. The sets had been taken from five fields at each of six different places, and to secure a single set of composite samples representing each area we mixed equal weights of soil from the corresponding depths of the five fields, making allowance for the unequal amounts of hygroscopic moisture at the time. Accordingly the average of the values for the various depths in each area represents the mean of 10 determinations. These data are given in the third column of Table XI. Later, samples of each of the 30 composites were exposed singly on three consecutive days. Only the one control soil, A, was used; on the first day the average value for this was found slightly higher and on the third slightly lower than on the second day. Of the 30 other soils 27 showed the highest value on the first day and 22 the lowest on the third day.

From the above the advantage of using samples of control soils will be evident. The mere concordance of determinations on different days and even by different operators is in itself no evidence that such data express the correct hygroscopic coefficients. Especially striking illustrations of this were afforded by the data obtained using pasteboard trays described above—data that we later wholly discarded. The development of an indirect method for the determination of the hygroscopic coefficient from the content of hygroscopic moisture was suggested by the parallel rise and fall of the two control soils from day to day (4, p. 348–359).

RELIABILITY OF THE METHOD DESCRIBED BY HILGARD

To determine this, we followed his method exactly, except that we used a table of paraffined wood, which he does not specify. To give the method the most severe test we each day employed fresh and, accordingly, air-dry sheets of glazed paper. Four soils, two of them of high hygroscopicity, were employed, they being exposed in duplicate for 12 hours and also for 24 hours (Table XII). During the whole of the time the temperature of the room was between 14° and 15° C.

TABLE XII.—*Results showing the reliability of Hilgard's method when carried out as he has described it*

Soil.	Hygroscopic coefficient.		
	On glazed paper.		In aluminum trays (24 hours' exposure).
	12 hours' exposure.	24 hours' exposure.	
Control soil L	15.4	15.7	16.0
Control soil I	19.5	20.0	21.5
Control soil A	5.2	5.3	5.6
Control soil C	.6	.6	.6

The data in Table XII show that in the case of soils of medium hygroscopicity a 12-hour exposure gives results so close to those obtained by one of longer duration or by the use of metal trays that the differences may be considered within the range of experimental error. However, in the case of soils of very high hygroscopicity, such as I, it is not certain that the results are not slightly too low; in the case of these it is especially important to have the layer of soil very shallow. With L and I we used only from 2 to 5 gm., 8 to 16 gm. giving a decidedly lower result, while with soil A 10 gm. was not too much and with C as much as 80 gm. could be used without lessening the value found.

It is highly important that the method of Hilgard, carried out exactly as he described it gives reliable results, as this makes available as trustworthy material for investigational purposes the great number of data on the hygroscopic coefficient which he has reported along with physical and chemical analyses of arid and humid soils.

MODIFICATIONS OF METHOD WHEN SAMPLE CONTAINS GRAVEL OR PEBBLES

On many soil types the sample in which moisture has been determined contains gravel or even small pebbles. These can not as such be included in the material exposed in the absorption boxes, as the quantity so used is so small that the coarse particles would constitute either a much smaller or much larger proportion of these than they did in the moisture sample. Accordingly they must either be separated and a correction introduced or be reduced to a state sufficiently fine to permit of a uniform sample being secured while still coarse enough to have practically no absorptive capacity. As a coarse sand has a hygroscopic coefficient of only about 0.5, the pebbles and gravel if crushed just sufficiently to pass a 2-mm. sieve will cause no difficulty on the trays and introduce no appreciable errors.

In practice we have found it most convenient to crush the sample in a steel mortar, sifting out the fine material at frequent intervals with a 2-mm. sieve.

CONCLUSIONS

The amount of hygroscopic moisture absorbed increases with the rise of temperature.

Drying of mineral soils at temperature of 100° to 110° C. does not appreciably decrease their hygroscopicity.

Intractable samples may be reduced in a steel mortar to pass a 1-mm. sieve without appreciably affecting their hygroscopicity.

Twelve hours' exposure in the absorption boxes is sufficient only when the soil layer is very shallow. In practice a longer interval is found more convenient, 20 to 24 hours proving very satisfactory. An exposure of

more than 24 hours gives higher values in the case of only very fine textured soils.

A soil containing the amount of moisture corresponding to its hygroscopic coefficient loses water very rapidly when exposed to an ordinarily dry atmosphere, but in determining the hygroscopic coefficient the time necessary to transfer the soils from the absorption boxes to weighing bottles is so brief that the loss during the transfer is too small to appreciably affect the accuracy of the results.

Hilgard's method for the determination of the hygroscopic coefficient, carried out exactly as he describes it, gives reliable results. However, the loose sheets of glazed paper thus involved are very inconvenient when many determinations are to be made and may advantageously be replaced by shallow trays, either of aluminum or of copper. Trays of glass, graniteware, and vulcanized rubber give satisfactory results, but are less convenient, while those of tin plate or zinc, although satisfactory at first, soon corrode. Pasteboard trays lined with glazed paper give results much too low, unless the period of exposure be greatly prolonged, and even those of paraffined pasteboard lined with glazed paper give somewhat low results. Any considerable increase in the size of the absorption boxes over that recommended by Hilgard or the use of a larger number of exposed samples within the boxes of the same size cause too low results, unless the time of exposure be greatly increased.

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INHERITANCE STUDIES IN PISUM. IV. INTERRELATION OF THE GENETIC FACTORS OF PISUM

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INTRODUCTION

The present paper describes and discusses the number of demonstrated factors in Pisum, their modifying effects upon each other's expression, the modification of their expression by different environments, and their relation to one another in inheritance, whether independent or linked.

MATERIAL AND METHODS

As pointed out by Mendel, Correns, Lock, and many others, the pea plant is in many respects especially favorable material for studying such genetic problems as these because of the ease with which it grows, its short life cycle, its practically complete self-pollination (1 to 10,000 in this locality) in outdoor cultures, its comparatively small number of chromosomes (seven pairs), the sharp cleavage in its multitudinous character differences, and the slight trouble involved in making successful crosses. On the other hand, back-crossing for various purposes, such as Morgan and his coworkers do, is practically out of the question with peas, because of the very small amount (2 to 4) of seed obtained from each cross for the amount of work required.

The material upon which the original and confirmatory data in this study are based consists of a collection of over 200 different varieties and species of peas gathered from all over the world through the help of the Offices of Foreign Seed and Plant Introduction and Forage-Crop Investigations; Sutton & Sons, Reading, England; P. Vilmorin and Vilmorin et Cie., Paris, France; W. Bateson and C. Pellew; Haage & Schmidt, Erfurt, Germany; several botanic gardens in Europe and Asia; and from many other sources. The material particularly used consists of the varieties listed in Table I, for which the factors directly concerned in this study are also given. All the strains have been inbred for at least two generations, and they breed true to the factors designated for them. All the pedigree cultures to be compared with one another were grown as nearly as practicable under the same environmental conditions—for example, the parents and the F_1 and F_2 generations are often grown side by side; crosses are practically all made in the greenhouse in winter; and the seed for growing the F_2 progeny are also grown under these conditions, as a greater quantity and better quality of seed can be secured than in field cultures. Under such conditions the bagging of emasculated flowers is absolutely unnecessary. Under extremely favorable conditions three generations a year can be grown, especially by using dwarf short-cycled

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types, such as P21. The forepart of the winter and late fall, however, is poor pea weather, because of the short daylight hours, so that generally at the Brooklyn Botanic Garden only two crops a year are matured.

TABLE I.—*Designation, source, and factorial composition of varieties of Pisum studied in determining the relation of factors to each other in inheritance*

No.	Variety.	Factors studied.[a]	Source.
1	Mummy	Ab(fa)G(Gp)I(Le)OR(Tl)	H. Eckford, Wem, England.
11	Quite Content	aB(Fa)(Le)	Vaughan Seed Co., New York.
12	Dwarf Grey Sugar	AB(le)T	Do.
13	Tall Grey Sugar	AB(Fa)GI(Le)pR	Do.
14	Black-eyed Marrowfat	G(Gp)I	Do.
21	Nott's Excelsior	aB(Fa)Gi(le)(Tl)	Peter Henderson & Co., New York.
22	First of All	aBGI(Le)OR	Do.
23	White-eyed Marrowfat	aB(Fa)I	Do.
26	Telephone	aB(Fa)Gi	Do.
27	Laxtonian	aB(Fa)Gi(le)	Do.
28	Aldermann	aB(Fa)Gi	Haage & Schmidt, Erfurt, Germany.
29	Späte Gold	aB(Fa)GI	Do.
30	Goldkönig	aB(Fa)g(Gp)i(Le)or(Tl)	Do.
32	Wachs Schwert	aB(bt)(Fa)G(gp)I(Le)OpR	Do.
35	"Market Split"	aB(Fa)G(Gp)iOR	New York City Markets.
36	Selection of MS (P35)	AB(Fa)	Do.
38	Acacia D	aB(Fa)Gi(le)rO(tl)	W. Bateson and C. Pellew.
39	Acacia T	aB(Bt)(Fa)Gi(Le)PR(tl)	Do.
40	*P. Jomardi*?	AB(Fa)GI(Le)OR(Tl)	Cambridge (England) Botanic Garden.
41	*P. elatius*	ABGI(Le)OPR(Tl)	Do.
43	*P. quadratum*	AB(Fa)I	W. Bateson and C. Pellew.
47	*P. sat. umbellatum*	aB(fa)	United States Department of Agriculture.
57	Quite Content	GiOr	Stumpp and Walters, New York.
58	Early White Dwarf Sugar.	aB(bt)(le)	Do.
59	Velocity	aBG(Le)R	Vaughan Seed Co., New York.
62	Everbearing	aBi(le)	Peter Henderson & Co., New York.
65	Yorkshire Hero	aBi(le)	Thorburn & Co., New York.
67	Advancer	aBGi(le)Pr	Peter Henderson & Co., New York.
72	Acacia V	aBGi(le)r(tl)	Vilmorin & Cie, Paris, France.
91	"Chenille"	aB(bl)s	P. Vilmorin, Paris, France.
94	Little Marvel	a(le)u	Sutton & Sons, Reading, England.
132	Abyssinian	ABI(Le)RU	Bureau of Plant Industry.
138	Benton	ABGIOR	United States Department of Agriculture.
198	Scotch Beauty	aBGiOR	Do.

[a] For key, see Table II.

Peas are easily crossed and the flowers but little affected by mutilation. The set of seed in good weather is, at least, 60 to 75 per cent. Of 200 or more varieties grown in the greenhouse in winter in 4-inch pots and in the open bench, none have failed to blossom and set seed.[1]

THE FACTORS OF PISUM

Mendel (1866)[2], Tschermak (1911), Correns (1902), Bateson (1909), Darbishire (1911), Lock (1905), Pellew (1913), Keeble (1910), Vilmorin (1911, 1913), Hoshino (1915), White (1916), and others have demonstrated, on the presence and absence hypothesis, the existence of over 35 factors in the genus Pisum, these obviously forming only a small part of the full factorial Pisum complex. If the experimental data secured by the above-mentioned investigators are interpreted on the "paired allelomorph" hypothesis, the "absence" of each factor is to be regarded as a recessive factor, and the number of demonstrated factors is thus increased to over 70. In Table II the factors are listed according to the "presence and absence" hypothesis. The presence and absence of these 35 factors gives rise, under certain specific environmental conditions, to over 70 differential Pisum characters.

The detailed experimental data by which these factors were demonstrated and the references to the literature, together with much other summarized data on the genetics of peas, are given in No. II of this series of studies on Pisum[3]; hence need not be repeated here. Suffice it to say that in many cases the existence of these factors has been proved by a large amount of experimental data, including large numbers of F_2 and F_3 generation individuals, results from the back-crossing of F_1 and homozygous F_2 and F_3 individuals with the ancestral "parent" types and with each other, reciprocal crosses, etc. With the exception of factors 11, 15, 17, 26, 27, and 33, the data are especially complete and satisfactory. In several cases studies on a single factorial difference have involved observations on over 20,000 individuals. In a large number of the cases the studies involve a thousand or more individuals. Most of these factors (except factors 13 and 24) have been isolated by other workers, but in many cases the writer has repeated their experiments with similar results.

In collecting these factors different symbols from those originally assigned them by their discoverers have often had to be given, in order to make them intelligible (Table II). Since the letters of the alphabet

[1] The writer is much indebted to his assistant, Miss M. Mann, and to Miss S. Streeter, a graduate student of the Brooklyn Botanic Garden, for assistance in collecting these data. Mr. Montague Free, of the Garden staff has also helped collect and classify the data.

[2] Bibliographic citations in parentheses refer to "Literature cited," p. 178–180.

[3] WHITE, O. E. INHERITANCE STUDIES IN PISUM. II. THE PRESENT STATE OF KNOWLEDGE OF HEREDITY AND VARIATION IN PEAS. Brooklyn Botanic Garden Contrib. 19. (Compilation and correlation of all the genetic data on Pisum up to 1916, with critical discussion and full bibliography. Read by title before the American Philosophical Society, May 4, 1917. Not yet published. Manuscript copy in Brooklyn Botanic Garden Library.)

are too few, double-letter expressions of a descriptive nature have been used, one capital and one lower-case letter, the two being joined by a parenthesis, as "(Gc)." In some cases, where two factors are responsible for the same result, the same letter, subtended by different numerals has been used by Tschermak (1911), and these are retained. The same factor often expresses itself in several distinct regions of the plant, such as the inflorescence, the leaf axils, etc. When more is known concerning the genetic behavior of some of these factors, two or more of them may be found to be absolutely coupled such as (1) [1] and (5), in which case matters are simplified by representing them by one factor symbol.

TABLE II.—*List of Pisum factors, alphabetically arranged, and their corresponding character expressions*

No.	Factor.	Expression.
1	A.....	Salmon-pink or rose flower color. With CD gives reddish leaf axils.
2	B.....	Purpling factor plus A gives purple flowers. With CD plus A gives purplish leaf axils and stem bases.
3	(Bl)	Glaucous foliage, stems and pods (with W); "bloom."
4	(Bt)....	Pods with blunt apex.
5	C[A]....	With D gives leaf axil and stem color.
6	D.....	With C gives leaf axil and stem color.
7	E[A]....	With F and B gives purple dotting on seed coats; in the absence of B gives reddish dots.
8	(Ef)....	Modifies the expression of (Lf) toward earlier flowering.
9	F.....	With E and B gives purple dotting on seed coats; in the absence of B gives reddish dots.
10	(Fa)....	Axillary flowers, round stems, regular phyllotaxy.
11	(Fn)....	1 to 2 flowers per peduncle.
12	(Gc)[A].	Yellowish green to grayish brown seed-coat color (weak chromogen factor), brown hilum.
13	G.....	Green cotyledon pigment.
14	(Gp)...	Green pod color.
15	H.....	Brightener or inhibitor of expression of Gc.
16	I.....	Factor which causes green cotyledon color to fade.
17	J.....	With (Gc) gives dark-brown seed-coat color.
18	L_1[A]...	With L_2 gives indent peas.
19	L_2.....	With L_1(A) gives indent or dimpled peas.
20	(Le)....	Long internodes; with T gives tall plants.
21	(Lf) ...	Primarily responsible for late flowering.
22	M.....	Brown or maple mottling on seed coat; or "ghost mottling" in absence of A.
23	N.....	Violet eye on seeds.
24	O.....	Green foliage, stems, and pods.
25	P.....	Inflated, parchmented, nonedible pods with V.
26	P_1.....	With P_2 gives purple pods.
27	P_2.....	With P_1 gives purple pods.
28	(Pl) ...	Black-eyed seed-coat pattern.
29	R.....	Round, smooth seeds with simple, oval starch grains, low water content and with excellent powers of germination under unfavorable weather conditions.
30	S.....	Pods with seeds separated or free.
31	T.....	Tall, robust plants, large number of internodes.
32	(Tl)...	Leaves with tendrils.
33	U.....	Dark self-colored purple seed coat.
34	V.....	With P gives parchmented, smooth pods.
35	W.....	With (Bl) gives glaucous foliage, pods.

[1] For key to numbers 1 to 35 in parentheses, see Table II.

Factors A, C, E, (Gc), and L_1, so far as the evidence forthcoming up to now is concerned, appear absolutely coupled, and it is much simpler to regard them all as one factor with many separate expressions. A could be substituted in each case where C, E, (Gc), and L_1 are used.

MODIFICATION OF THE EXPRESSION OF PISUM FACTORS BY DIFFERENT ENVIRONMENTS AND BY EACH OTHER

Most of these data have been compiled from other papers, but this brief review also represents for the most part, first-hand confirmatory knowledge by the writer. References to literature and credit are given in the earlier paper previously referred to.[1]

The factor expressions given in Table II represent only the usual or common expression, and changes in environment may quite radically modify these expressions. Weather conditions, especially prolonged damp or rainy weather, often wash out or suppress the development of the purple flower color, so that it resembles the pink, and pinks are modified by the same causes to white. Under greenhouse conditions, where proper control is exercised, this never happens. Factors 3 and 35, either independently of each other or when combined, produce the glaucous waxy covering of peas. Factor 3 is arbitrarily regarded as the common one. Plants from which either or both of these are absent are called "emeralds," and lack this covering. Such plants are very subject to death from disease and other external causes; hence, are generally deficient in number in the F_2 ratios from crosses of glaucous with emerald varieties. The usual expression of factor (Bt) (4) depends partly on whether the pod is well filled with peas. Factors C and D (5, 6) are dependent on plenty of sunlight; otherwise the color is either completely absent or faint. The anthocyanin pigment of the seedcoat pattern, brought about by the presence of factors E and F (7, 9) is soluble in water and may be washed out in rainy weather. Factors (Ef) and (Lf) (8, 21) are modified by a large number of environmental conditions, so that studies on these should always be carried on with parents, F_1, F_2s, etc., growing side by side from plantings made at the same time. In crosses between certain normal and fasciated varieties of peas, dominance may be partially reversed by cloudy weather and conditions very favorable for rank growth. Unfasciated stem is usually dominant over fasciated stem, but in such crosses as noted above, the F_1 plants have been slightly fasciated under the conditions mentioned, while under other conditions, F_1 plants of the same cross have remained normal.

A character similar to that produced by the absence of factor (Fa) (10) may be brought about in varieties of peas in which (Fa) is present by very damp weather, lack of sufficient sunlight, and crowding and twisting of the stems (White, 1916b). Various environmental causes

[1] White, O. E. Op. cit.

bring about fasciation in plants, but in the case of such varieties of peas as the Mummy (P1), the cause is innate or hereditary.

The expression of (Gc) (12) changes to a deeper brown, resembling that of (Gc) (12) and J (17) combined, if the ripe seeds remain exposed to the weather or even ripen under conditions of much alternation of sun and rain. Under greenhouse conditions water rarely touches the ripe seeds. The expression of factor G (13) fades on prolonged exposure to sunlight and wet weather, and seeds of wrinkled-seeded varieties fade more quickly than those of green round-seeded forms. Lack of sufficient sunlight, immaturity due to prolonged growth of the vine, and other environmental factors effect the action of factor I (16) on green cotyledon pigment, especially in such varieties as Späte Gold (P29). Pitting or "spurious indent" resembling the expression of factors L_1 (18) and L_2 (19) is found as an environmental effect in peas from which these factors are absent. This is commonly the case in field-grown seeds in this locality of such white-flowered, round-seeded varieties as Tall Acacia (P39), First of All (P22), and Black-Eyed Marrowfat (P14). Factor (Le) (20) is generally responsible for the difference between dwarf and tall peas, and this difference may be noted as soon as the plants are 2 to 3 weeks old. Factor T (31), aside from the fluctuations caused by differences in environment, is responsible for the number of internodes. Pea varieties may be classified into three general types as regards height—dwarfs, half dwarfs, and talls. Dwarfs have 8 to 15 short internodes. Half dwarfs are at least of two general types—plants with 10 to 18 long internodes or 20 to 30 short ones. Tall peas are made up of a large number of long internodes (35 to 60). Other hereditary elements not yet isolated, together with environmental conditions such as disease, very poor soil, and dry, hot weather, modify the expression of these factors, especially T (31). The absence of factor (Fa) (10), bringing about fasciation, modifies height by shortening the internodes, though possibly the number of internodes is increased. Factor M (22) expresses itself very faintly ("ghost mottling") in the absence of factor A (1) for flower color. Prolonged exposure to sun and rain after the seeds are mature darkens the brown pigment.

The expression of factor O (24) may be modified or almost entirely suppressed by certain diseases or the lack of sufficient salts, such as potassium. Sickly yellow foliage results, somewhat resembling varieties from which O is absent, though whiter and duller. Crosses involving factors G, O, and R (13, 24, 29) apparently give complex results. Either the presence of the shape factor R (29) causes no zygotes to be formed in which R is present and G and O are absent, or the presence of R in some way brings about the production of green pigment, even though G (13) is absent. More data are being accumulated, and it is hoped these particular problems will be solved shortly through their aid. The expression of factor S (30), in the absence of which pea seeds are

stuck together when mature, is regarded by the Hagedoorns (1914) as being modified by the factors for flower color and glaucous foliage and stems. In working over Vilmorin's data (1913), the present writer concluded that these data were more simply explained by regarding factors (Bl) (3) and S (30) as partially coupled or linked and by assuming certain of the F_2 combinations to be adversely affected by weather conditions. The variety with stuck-together seeds ("chenille") has emerald foliage, but emerald varieties are known with free seeds.

RELATION OF PISUM FACTORS TO EACH OTHER IN INHERITANCE, WHETHER LINKED (COUPLED) OR INDEPENDENT

The studies of Bateson (1909), Pellew (1913), Surface (1916), Tanaka (1913), Emerson (1911), Vilmorin (1913), Gregory (1911), Doncaster (1913), Pearl (1912), Altenburg (1916), and especially of Morgan and his coworkers and students (1915), Sturtevant (1915), Bridges (1914), and Muller (1916) make it increasingly evident that the various hereditary characteristics of organisms and their determiners or factors are inherited in more or less closely linked groups, instead of independently, as was supposed in the early Mendelian studies, these groups being held together, perhaps, by chromosomes. As shown by Cannon (1903), Strasburger (1911), and others, at least some varieties of the common pea have seven pairs of chromosomes; and a wide cytological investigation, now in progress, will determine how true this is for all species of Pisum. On the assumption that seven pairs of chromosomes are the number usually present in all varieties, the number of independently inherited groups in Pisum, on the chromosome hypothesis as developed by Morgan and his students (1915), should be seven. Should accurately checked data show that more than seven of these groups occur, for instance, eight or nine, either the varieties used possess more than seven pairs of chromosomes or the chromosome theory as now held, so far as peas are concerned, would need revision or would be disproved. The chromosomes of peas, as compared with those of *Drosophila* spp., however, are long; and from this fact one might assume the linear distances between many of the factors to be greater. This being true, greater opportunities for crossing over would occur, and when the number of cross-overs approached 50 per cent, greater difficulty would be found in securing sufficiently accurate data to distinguish between ratios involving linkage and those showing only independent inheritance.

Table III shows the totals of F_2 ratios from crosses involving the presence and absence of eight factors [A, B, (Fa), I, (Le), G, R, (Tl)], two of which [R and (Tl)] belong to one group. Each factor has been tested out in crosses involving all its possible combinations with the other seven, the results indicating seven independently inherited groups in Pisum. Hence, in Table III all the factors of one group have a common number, as, for example, R and (Tl) meaning that both R and (Tl) belong to group 7. The F_2 generation totals in most cases are fairly large and dependable,

but in some cases still more data are needed, in view of the fact that the linked groups may be less closely bound together in Pisum than in Drosophila, because of difference in chromosome dimensions. In several cases, involving small totals, the approximation between the classes actually obtained and those theoretically expected is not very close. As soon as more data are obtainable probable errors for these ratios will be calculated. In Table III, the ratios actually obtained are given first and the calculated expectation directly beneath. Each factorial combination is separated by a line and the combinations themselves (somatic) are expressed by descriptive character symbols, explanations of which are given in a note below the table. Factors (Tl) and R are used interchangeably, as they are closely linked. The totals represent the F_2 populations from crosses of different varieties, though each of the two varieties involved in a single cross differed in the designated factors. The data from the individual crosses with the numbered designations of the varieties involved, are given in the appendix. Each group of crosses involving one type of factorial difference is designated so as to correspond with the designation in Table III, as *exempli gratia* (1), (2), etc. All data except those involving group 7 are from the Brooklyn Botanic Garden cultures. The data for group 7 are the combined results from the studies of Vilmorin (1911), Bateson (1909), Bateson et al. (1905), Pellew (1913), as well as from the writer's own studies.

The employment of data from crosses involving many different varieties to demonstrate the independent inheritance of specific factors, such as those given in Table III, as compared with data from crosses involving only two varieties with the desired factorial differences, is open to some criticism on the hypothesis of multiple factors. Nilsson-Ehle, (1908, 1909), East (1910), Morgan et al. (1915), Shull (1914), and many others have secured F_2 ratios involving only one character difference, which, however, gives a di-, tri-, or poly-hybrid ratio.

Apparently the same characters in plants and animals of the same species in other experiments have given an ordinary monohybrid 3 : 1 or 1 : 2 : 1 F_2 ratio. These results (dark-brown glume color in oats, yellow endosperm color in maize, pink eye color in Drosophila, capsule-shape in shepherd's-purse (*Bursa bursa-pastoris*), etc., are interpreted by their discoverers as showing the presence of two (in case of a dihybrid ratio) or more factors, each of which by itself gives rise to practically the same effect, expression or character, as when both are concerned. Further, as the ratio indicates, they are inherited independently of each other, and according to Morgan, Sturtevant, and their colleagues (1915), they are located in different chromosomes. By the method in use in the present study, different factors in different varieties giving the same or very nearly the same "somatic" expression could not be distinguished; hence, one can not be certain that he is always experimenting with the same factor.

TABLE III.—*Frequency distribution actually obtained and theoretically expected of the various factorial combinations of F_2 populations of peas derived from crosses involving eight pairs of factorial differences, two of which are partially linked*

No.	Factors.	F_2 frequency ratio.[a]
1	A^1, $(Fa)^3$	25 RpN : 7 RpF : 6 WN : 1 WF.
	Total 39	22 RpN : 7 RpF : 7 WN : 2.4 WF.
2	A^1, B^2, $(Fa)^3$	823 RpN : 264 RpF : 260 PN : 68 PF : 401 WN : 120 WF.
	Total 1,936	817 RpN : 272 RpF : 272 PN : 90 PF : 363 WN : 121 WF.
3	B^2, $(Fa)^3$	323 RpN : 94 RpF : 100 PN : 33 PF.
	Total 550	309 RpN : 103 RpF : 103 PN : 34 PF.
4	A^1, B^2, I^4	332 RpY : 103 RpG : 112 PY : 26 PG : 150 WY : 54 WG.
	Total 777	327 RpY : 109 RpG : 109 PY : 36 PG : 145 WY : 48 WG.
5	$(Fa)^3$, I^4	411 YN : 129 YF : 115 GN : 43 GF.
	Total 698	392 YN : 131 YF : 131 GN : 44 GF.
6	A^1, B^2, $(Le)^5$	179 RpT: 64 RpD : 50 PT : 19 PD : 73 WT : 31 WD.
	Total 416	175.5 RpT : 58.5 RpD : 58.5 PT : 19.5 PD : 78 WT : 26 WD.
7	A^1, $(Le)^5$	750 RpT : 270 RpD : 276 WT : 84 WD.
	Total 1,382	776.7 RpT : 259 RpD : 259 WT : 86.3 WD.
8	$(Fa)^3$, $(Le)^5$	233 NT : 82 ND : 69 FT : 32 FD.
	Total 416	234 NT : 78 ND : 78 FT : 26 FD.
9	I^4, $(Le)^5$	669 YT : 255 YD : 225 GT : 83 GD.
	Total 1,232	693 YT : 231 YD : 231 GT : 77 GD.
10	A^1, B^2, I^4, G^6	80 RpY : 13 RpG : 28 PY : 5 PG : 30 WY : 11 WG.
	Total 167	76.0 RpY : 17.5 RpG : 25.3 PY : 5.8 PG : 33.8 WY : 7.8 WG.
11	A^1, I^4, G^6	168 CY : 32 CG : 52 WY : 13 WG.
	Total 265	160 CY : 36.9 CG : 53.3 WY : 12.3 WG.
12	$(Fa)^3$, G^6	102 YN : 36 YF : 25 GN : 4 GF.
	Total 167	101.4 YN : 34 YF : 23.4 GN : 7.8 GF.
13	I^4, G^6	1,142 Y : 268 G.
	Total 1,410	1,145.3 Y : 264.3 G.
14	$(Le)^5$, G^6	22 GT : 6 GD : 7 YT : 1 YD.
	Total 36	20.25 GT : 6.75 GD : 6.75 YT : 2.25 YD.
15	A^1, R^7	317 RRp : 106 RW : 113 WrRp : 43 WrW.
	Total 579	324.9 RRp : 108.3 RW : 108.3 WrRp : 36 WrW.
16	A^1. $(Tl)^7$	233 TlRp : 77 TlW : 68 ARp : 26 AW.
	Total 404	226.8 TlRp : 75.6 TlW : 75.6 ARp : 25.2 AW.
17	B^2, $(Tl)^7$	53 TlB : 10 AB : 14 Tlb : 2 Ab.
	Total 79	45 TlB : 15 AB : 15 Tlb : 5 Ab.
18	$(Fa)^3$, $(Tl)^7$	(No coupling; figures not available (Pellew).
		50+1? TNL : 5+1? NA : 16 TlF : 5+1? AF.
	Total 79	45 TlN : 15 NA : 15 TlF : 5 AF.
19	I^4, R^7	5,241 RY : 1,729 RG : 1,757 WrY : 510 WrG.
	Total 9,237	5,195 RY : 1,731 RG : 1,731 WrY : 577 WrG.
20	I^4, $(Tl)^7$	273 TlY : 94 TlG : 82 AY : 32 AG.
	Total 481	270.2 TlY 90.2 TlG : 90.2 AY : 30.2 AG.
21	$(Le)^5$, $(Tl)^7$	(No coupling; figures not available (Pellew).
	Total 96	51 TlT : 25 TlD : 13 AT : 7 AD.
		54 TlT : 18 TlD : 18 AT : 6 AD.
22	$(Le)^5$, R^7	73 RT : 34 RD : 28+1? WrT : 7 WrD.
	Total 143	80.1 RT : 26.7 RD : 26.7 WrT : 8.9 WrD.
23	G^6, $(Tl)^7$	31 GTl : 13 GA : 19 YTl : 5 YA.
	Total 68	37.8 GTl : 12.6 GA : 12.6 YTl : 4.2 YA.

[a] Rp=purple flower color; P=pink flower color; W=white flower color; C=colored flowers. N=normal stems; F=fasciated stems. Y=yellow cotyledon color; G=green cotyledon color. T=long internodes (tall plants); D=short internodes (dwarf plants). R=round cotyledons; Wr=wrinkled cotyledons. Tl=leaves with tendrils; A=leaves without tendrils (acacia). B and b=with and without factor B.

Two such multiple factors as A and A_1, each capable of producing pink flower color, each located in a separate chromosome, and each independently inherited from a third such factor A_2, having the same expression, could bring about considerable confusion in such an attempt as the present to determine the factorial groups of Pisum. With data from crosses of two varieties having seven or more factorial differences, no such difficulties would be encountered, and perhaps even with the method used above the chance of encountering more than one such factor, is comparatively rare. As soon as two true breeding varieties differing in seven or more suitable factors can be secured from crossing experiments the independence in inheritance of the factors listed in Table III will again be tested.

From among 16,384 or more F_2 progeny of such a cross, if each factor proved again to be independently inherited, there should be over 128 (2^7) visibly distinct forms, representing 2,187 distinct factorial combinations. Provided the cross involved 8 factor differences, each inherited independently of the other, 256 distinct forms would be theoretically expected and if a cross were made involving 25 such factor differences, each independently inherited, the F_2 generation, if it were practicable to grow a large enough population (4^{25}), should consist of at least (2^{25}) 33,554,432 visibly distinct forms. The classification of such a population, even when obtained, would be impracticable, if not impossible.

It is brought into the present discussion to emphasize the enormous amount of variation possible through crossing, for even on the chromosome-crossing-over-linkage hypothesis of Morgan and his coworkers (1915), plants and animals are known with more than enough factor differences and chromosomes to have 25 independently inherited groups. For example, *Nicotiana tabacum*, the commercial tobacco, as observed by the writer (1913), has 24 chromosome pairs and the recent lists of Tischler (1916) and Ishikawa (1916) cite plants with a much higher number. As pointed out by East (1915), if the facts and theories regarding inheritance in *Drosphila* spp. are found to be true for organisms in general, it is very important that plant breeders should know the number of chromosome pairs in the plants with which they are experimenting. When one contrasts the number of forms that can be derived from such crosses as mentioned above with the number of recognized plant species (approximately 225,000) and considers that to the plant breeder and horticulturist many of these forms are as distinct as taxonomic species, one is not surprised at all that a certain well-known taxonomist and student of phylogeny, Lotsy (19), should advocate that all evolutionary change of a hereditary nature is due to crossing.

Other factors in addition to those listed in Table III have been tested out with each other, but only part of the possible combinations with those given in Table III have been made, so these data are reserved for a later paper.

LINKAGE IN PISUM

In Table IV the available data on linkage of factors in Pisum are given. As in Table III, only totals are listed, the detailed results from which the totals were compiled being given in the appendix, the tables being numbered to correspond with the linked factor groups in Table IV. Linked group 24 in Table IV is based on the writer's own interpretation of Vilmorin's (1911) data from F_2 hybrid populations and F_3 progeny from heterozygotes similar to the F_1. The deficiency of EA individuals is, as previously stated, probably due to insufficient ability to resist disease. At least, that is the writer's own experience with emerald varieties. The calculation of crossover to non-crossover gametes is based on Castle's table (1916).

Group 25 is based on the studies of Lock (1905), Tschermak (1911), and Hoshino (1915), supplemented by the writer's own studies, though none of his own data are incorporated. The figures and interpretation are taken from Hoshino's paper. As previously stated, factors A, C, E, (Gc), and L_1, are absolutely coupled and most simply interpreted as expressions of A, instead of as five distinct factors, as held by Tschermak and others. Group 26 is based on the data and the interpretation of Vilmorin and Bateson (1911), and Pellew (1913), though the discovery was first made by Vilmorin (1911). The results of the writer from numerous crosses, among which was one, the F_2 seed of which was kindly sent me by Prof. Bateson, completely confirm the previous studies. Group 27 is based entirely on the writer's own data, but they are too few as yet to determine the ratio of non-crossover to crossover gametes. Groups 25, 26, and 27 are inherited independently of each other, but, as shown in Table III, they belong to three of the seven independently inherited groups already demonstrated. The relation of group 24 to these, so far as the writer is aware, is undetermined.

TABLE IV.—*Linked groups of Pisum* [a]

No.	Factors.	Linkage.
24	(Bl), S.....	265 GlFs : 6 GlAs : 12 EFs : 57 EAs.
	Total 340.....	226 GlFs : 17 GlAs : 17 EFs : 64 EAs (8:1).
		189.9 GlFs : 63.3 GlAs : 63.3 EFs : 21.1 EAs (no coupling).
25	A (Lf).....	513 WE : 163 WL : 141 RpE : 1813 RpL.
	Total 2,636....	505 WE : 154 WL : 154 RpE : 1823 RpL (7:1).
		164.3 WE : 492.9 WL : 492.9 RpE : 1478.7 RpL (no coupling).
25	A, C, E (Gc), and L_1	Absolutely coupled, so may be regarded as expressions of a single factor A.
26	R (Tl).....	1,466 RT : 20 RA : 15 WT : 564 WA.
	Total 2,065....	1,471 RT : 15 RA : 15 WT : 561 WA (63:1).
		1,161 RT : 387 RA : 387 WT : 129 WA (no coupling).
27	G, O.....	134 GcGf : 6 GcYf (?) : 16 YcGf (?) : 40 YcYf.
	Total 196.....	109.7 GcGf : 36.3 GcYf (?) : 36.3 YcGf (?) : 12.2 YcYf (no coupling).

[a] Actually obtained F_3 classes and frequencies given first, followed (1) by approximated amount of crossing-over and (2) by theoretical expectancy on a non-linked or no-coupling basis.
Gl = glaucous, E = emerald or non-glaucous Fs = free seeds, As = adhering or "chenille" seeds.

SUMMARY

(1) Thirty-five genetic factors of the genus Pisum together with their common expressions, are listed and discussed in the present paper. The "presence and absence" of these 35 factors are mainly responsible for 70 or more differential Pisum characters.

(2) The modifying effects of the expression of one factor upon that of another, and the effects of external environmental conditions upon the expression of these factors, so far as known, are presented and discussed.

(3) Data, involving many thousand F_2 generation progeny, indicate the factors A, B, (Fa), I, (Le), G, and R to be independently inherited—that is, not linked, unless the linkage is very loose.

(4) Data for four linked groups are presented, three of which involve the factors mentioned under (3), and one of which the relations to the above seven are still undetermined.

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APPENDIX

[See pages 173–177]

TABLE 1.—*Inheritance of factors A and (Fa)*

Cross.	F_2 classes and frequencies.				Total.
	RpN.	RpF.	WN.	WF.	
(P47–1×P40–4)–1	25	7	6	1	39
Theoretically expected	22	7	7	2.4	39
Ratio	9	3	3	1	.....

TABLE 2.—*Inheritance of factors A, B, and (Fa)*

Cross.	F_2 classes and frequencies.						Total.
	RpN.	RpF.	PN.	PF.	WN.	WF.	
(P1−4×P23−4)−1.	45+3?	15	12	2	24	7	108
(P1−4×P32−5)−1.	4	2	1	0	3	1	11
(P1−4×P32−5)−3.	0	1	1	0	1	0	3
(P1−4×P32−5)−4.	13+4?	6	3	0	11	3	40
(P1−4×P39−3)−1.	34	9	11	5	12	8	79
(P1−6×P29−1)−1.	3	1	4	1	4	1	14
(P11−1×P1−1)−1.	33+1?	3	7	5	10	1	60
(P11−1×P1−1)−2, −3, −4.....	34	15	13	2	17	5	86
(P11−1×P1−2)−1.	21	12	6	3	18	4	64
(P21−1×P1−1)−1, etc.....	172	54	44	18	70	25	383
(P23−1×P1−2)−1, −2.....	80	17+1?	22	5	41+1?	9	176
(P26−1×P1−1)−1, −2, −3, −4.....	38	12	16	5	21	5	97
(P27−1×P1−1)−1.	15	2	7	0	7	2	33
(P28−1×P1−1)−1, −2.....	66	26	30	6	36	13	177
(P28−2×P1−2)−1, −2.....							
(P29−1×P1−4)−2, −3, −4.....	47	19	10	2	25	11	114
(P30−1×P1−1)−1, etc.....	69	24	27	6	31	10	167
(P32−1×P1−4)−1, −2.....	117	38	39	7	56	13	270
(P35−3×P1−4)−1, −2.....	24	7	7	1	13	2	54
Grand total...	815+8?	263+1?	260	68	400+1?	120	1,936
Theoretically expected ...	816.7	272.2	272.2	90.7	363	121	1,936
Ratio.....	27	9	9	3	12	4	.....

TABLE 3.—*Inheritance of factors B and (Fa)*

Cross.	F_2 classes and frequencies.				Total.
	RpN.	RpF.	PN.	PF.	
P1−1×Red-flowered Normal.....	52	12+2?	14+1?	3	84
Do.....	100+2?	29+1?	38+1?	11+2?	184
(P13−1×P1−1)−1.....	79+5?	26+1?	27	11	149
(P13−3×P1−3)−1, −2.....	81+3?	20+2?	19	6	131
(P36−1×P1−6)−1.....	1	1	0	0	2
Grand total.....	313+10?	88+6?	98+2?	31+2?	550
Theoretically expected.....	308.7	102.9	102.9	34.3	550
Ratio.....	9	3	3	1	.....

TABLE 4.—*Inheritance of factors A, B, and I*

Cross.	F_2 classes and frequencies.						Total.
	RpV.	RpG.	PV.	PG.	WY.	WG.	
(P1−4×P39−3)−1	28	15	11	5	15	5	79
(P21−1×P1−1)−1, etc	176	50	53	9	71	24	383
(P26−1×P1−1)−1, −2, −3, −4	36	7	13	3	16	9	84
(P28−1×P1−1)−1, −2, etc	73	19	28	8	34	15	177
(P35−3×P1−4)−1, −2	19	12	7	1	14	1	54
Grand total	332	103	112	26	150	54	777
Theoretically expected	326.7	108.9	108.9	36.3	145.2	48.4	777
Ratio	27	9	9	3	12	4	.....

TABLE 5.—*Inheritance of factors (Fa) and I*

Cross.	F_2 classes and frequencies.				Total.
	YN.	YF.	GN.	GF.	
(P21−1×P1−1)−1, etc	226	74	60	23	383
(P26−1×P1−1)−1, −2, −3, −4	50	15	14	5	84
(P28−1×P1−1)−1, −2, etc	102	33	30	12	177
(P35−3×P1−4)−1, −2	33	7	11	3	54
Grand total	411	129	115	43	698
Theoretically expected	392.4	130.8	130.8	43.6	698
Ratio	9	3	3	1	.....

TABLE 6.—*Inheritance of factors A, B, and (Le)*

Cross.	F_2 classes and frequencies.						Total.
	RpT.	RpD.	PT.	PD.	WT.	WD.	
(P21−1×P1−1)−1, etc	167	59	43	19	65	30	383
(P27−1×P1−1)−1	12	5	7	0	8	1	33
Grand total	179	64	50	19	73	31	416
Theoretically expected	175.5	58.5	58.5	19.5	78	26	416
Ratio	27	9	9	3	12	4	.....

TABLE 7.—*Inheritance of factors A and (Le)*

Cross.	F_2 classes and frequencies.				Total.
	RpT.	RpD.	WT.	WD.	
(P21−1×P1−1)−1, etc.	167	59	65	30	321
(P27−1×P1−1)−1	12	5	8	1	26
(P40−1×P58−2)−1,−2	25	8	12	2	47
(P41−1×P21−1)−1,−2	122	36	40	8	206
(P41−3×P58−3)−1	23	6	5	1	35
(P58−3×P41−5)−1,−2	82	21	34	4	141
(P62−1×P41−3)−1,−2	67	16	20	4	107
(P65−1×P41−3)−1	37	22	10	4	73
(P67−6×P13−3)−1,−2,−3	39	15	26	4	84
(P72−1×P41−5)−1,−2	176	82	56	26	340
Grand total	750	270	276	84	1,380
Theoretically expected	776.7	258.9	258.9	86.3	1,380
Ratio	9	3	3	1	.....

TABLE 8.—*Inheritance of (Fa) and (Le)*

Cross.	F_2 classes and frequencies.				Total.
	NT.	ND.	FT.	FD.	
(P21−1×P1−1)−1, etc.	210	76	65	32	383
(P27−1×P1−1)−1	23	6	4	0	33
Grand total	233	82	69	32	416
Theoretically expected	234	78	78	26	416
Ratio	9	3	3	1	.....

TABLE 9.—*Inheritance of factors I and (Le)*

Cross.	F_2 classes and frequencies.				Total.
	YT.	YD.	GT.	GD.	
(P21−1×P1−1)−1, etc.	221	79	54	29	383
(P41−1×P21−1)−1,−2	121	34	42	11	208
(P62−1×P41−3)−1,−2	71	20	29	5	125
(P65−1×P41−3)−1	38	20	17	9	84
(P67−6×P13−3−3)−1,−2,−3	51	15	15	6	87
(P72−1×P41−5)−1,−2	167	87	68	23	345
Grand total	669	255	225	83	1,232
Theoretically expected	693	231	231	77	1,232
Ratio	9	3	3	1	.....

TABLE 10.—*Inheritance of factors A, B, I, and G*

Cross.	F_2 classes and frequencies.						Total.
	RpY.	RpG.	PY.	PG.	WY.	WG.	
(P30−1×P1−1)−1, etc	80	13	28	5	30	11	167
Theoretically expected	76.0	17.5	25.3	5.8	33.8	7.8	167
Ratio	117	27	39	9	52	12	.....

TABLE 11.—*Inheritance of factors A, I, and G*

Cross.	F_2 classes and frequencies.				Total.
	CY	CG	WY	WG	
(P30−1×P1−1)−1, etc	108	18	30	11	167
(P40−2×P30−4)−1	60	14	22	2	98
Grand total	168	32	52	13	265
Theoretically expected	160	36.9	53.3	12.3	265
Ratio	39	9	13	3	.....

TABLE 12.—*Inheritance of factors (Fa) and G*

Cross.	F_2 classes and frequencies.				Total.
	YN	YF	GN	GF	
(P30−1×P1−1)−1, etc	102	36	25	4	167
Theoretically expected	101.4	33.8	23.4	7.8	167
Ratio	39	13	9	3	.....

TABLE 13.—*Inheritance of factors G and I*

Cross.	F_2 classes and frequencies.		Total.
	Y	G	
Dom. Y (GGII)×rec. Y (ggii)[a]			
Total data transferred from table 3b (1916)	457	87+22?	566
(P29−2−1×P30−A−10)−1	78	17	95
(P29−2−1×P30−A−10)−2	155	40	195
(P29−2−1×P30−A−10)−3	75	19	94
(P29−2−2×P30−A−11)−1	108	25	133
(P138−1×P30−4−1)−1	28	10	38
(P138−2×P30−4−1)−1	140	30	170
(P138−2×P30−4−1)−2	72	16	88
(P71−2−2−1×P30−4−3−1)−1	4	0	4
(P90−3−1×P30−4−3−1)−1	11	1	12
(P90−3−1×P30−4−3−1)−2	9	1	10
(P100−3−1×P30−4−3−1)−2	5	0	5
Grand total	1, 142	246+22?	1, 410
Theoretically expected	1, 145. 3	264. 3	1, 410
Ratio	13	3	.....
Dom. Y×G cot. (GGii)[a]			
For crosses, *etc.*, see Darbishire (1913, p. 71) and White (1916, pp. 537–538)	43, 764	14, 490	58, 254
Theoretically expected	43, 690. 5	14, 563	58. 254
Ratio	3	1	.....
Rec. Y×G cot.			
(P21−15−1×P30−A−2)−1	5	22	27
(P21−15−1×P30−A−2)−2	8	23	31
(P30−5−4×P38−20−1P)−1	15	49	64
(P30−5−4×P38−20−1P)−2	11	41	52
(P30−5−4×P38−20noP)−1	6	26	32
(P30−5−1×P38−20−1)−1	12	31	43
(P57−2×P30−5−7)−1	3	13	16
(P57−2×P30−5−7)−2	3	12	15
Grand total	63	217	280
Theoretically expected	70	210	280
Ratio	1	3	.....

[a] Factorial composition.

TABLE 14.—*Inheritance of factors (Le) and G*

Cross.	F_2 classes and frequencies.				Total.
	GT	GD	YT	YD	
(P21−15−1×P30−A−2)−1,−2	22	6	7	1	36
Theoretically expected	20.2	6.7	6.7	2.2	36
Ratio	9	3	3	1	.....

TABLE 15.—*Inheritance of factors A and R*

Cross.	F_2 classes and frequencies.				Total.
	RRp	RW	WrRp	WrW	
(P40−2×P30−4)−1	55	20	19	4	98
(P41−1×P30−6)−1	32	10	7	2	51
(P67−6×P13−3−3)−1,−2,−3	45	21	12	9	87
(P72−1×P41−5)−1,−2	185	55	75	28	343
Grand total	317	106	113	43	579
Theoretically expected	324.9	108.3	108.3	36.1	579
Ratio	9	3	3	1	.....

TABLE 16.—*Inheritance of factors A and (Tl)*

Cross.	F_2 classes and frequencies.				Total.
	TlRp	TlW	ARp	AW	
(P72−1×P41−5)−1,−2	197	60	61	22+1?	.....
(P1−4×P39−3)−1	35+1?	17	5+2?	3	.....
Grand total	232+1?	77	66+2?	25+1?	404
Theoretically expected	226.8	75.6	75.6	25.2	404
Ratio	9	3	3	1	.....

TABLE 17.—*Inheritance of factors B and (Tl)*

Cross.	F_2 classes and frequencies.				Total.
	TlB.	AB.	Tlb.	Ab.	
(P1−4×P39−3)−1	52+1?	8+2?	14	2	79
Theoretically expected	45	15	15	5	79
Ratio	9	3	3	1	.....

TABLE 18.—*Inheritance of factors (Fa) and (Tl)*

Cross.	F_2 classes and frequencies.				Total.
	TlN.	AN.	TlF.	AF.	
(P1−4×P39−3)−1	50+1?	5+1?	16	5+1?	79
Theoretically expected	45	15	15	5	79
Ratio	9	3	3	1	.....

TABLE 19.—*Inheritance of factors I and R*

Cross.	F_2 classes and frequencies.				Total.
	RY.	RG.	WrY.	WrG.	
Data from Bateson, Saunders, and Punnet (1905)	4, 926	1, 621	1, 656	478	8, 681
From Mendel's data (1865, p. 19)	315	108	101	32	556
Grand total	5, 241	1, 729	1, 757	510	9, 237
Theoretically expected	5, 195	1, 731	1, 731	577	9, 237
Ratio	9	3	3	1	.....

TABLE (20).—*Inheritance of factors I and (Tl)*

Cross.	F_2 classes and frequencies.				Total.
	TlY.	TlG.	AY.	AG.	
(P1−4×P39−3)−1	45	21	8	4	78
(P39−1×P32−1)−1	37	6	10	4	57
(P72−1×P41−5)−1, −2	191	67	64	24	346
Grand total	273	94	82	32	481
Theoretically expected	270. 2	90. 2	90. 2	30. 2	481
Ratio	9	3	3	1	.....

TABLE 21.—*Inheritance of factors (Le) and (Tl)*

Cross.	F_2 classes and frequencies.				Total.
	TlT.	TlD.	AT.	AD.	
(P38−1×P35−7)−1	26	16	10	4	56
(P30−5×1−P38−20−1)−1, etc.	25	9	3	3	40
Grand total	51	25	13	7	96
Theoretically expected	54	18	18	6	96
Ratio	9	3	3	1	.....

TABLE 22.—*Inheritance of factors (Le) and R*

Cross.	F_2 classes and frequencies.				Total.
	RT.	RD.	WrT.	WrD.	
(P38−1×P35−7)−1	26	17	10	3	56
(P67−6×P13−3−3)−1, −2, −3	47	17	18+1?	4	87
Grand total	73	34	28+1?	7	143
Theoretically expected	80. 1	26. 7	26. 7	8. 9	143
Ratio	9	3	3	1	.....

TABLE 23.—*Inheritance of factors G and (Tl)*

Cross.	F_2 classes and frequencies.				Total.
	GTl.	GA.	YTl.	YA.	
(P30−5−1×P38−20−1)−1	16	12	8	2	38
(P30−5−4×P38−20−1)−1P	15	1	Not recorded.		16
(P30−5−4×P38−20−1)−1	Not recorded, but no indication of coupling.		11	3	14
Grand total	31	13	19	5	68
Theoretically expected	37. 8	12. 6	12. 6	4. 2	68
Ratio	9	3	3	1	.....

TABLE 24.—*Inheritance of factors (Bl) and S*

Cross.	F_2 etc. classes and frequencies.[a]				Total.
	GlFs.	GlAs.	EFs.	EAs.	
Mummy×Chenille F_2 generation[b]	138	2	6	31	177
F_3 progeny of F_2 double heterozygote	57	0	2	21	80
Do.	70	4	4	5	83
Grand total	265	6	12	57	340
Calculated on 8:1[c] basis	226	17	17	64	324
Calculated on no-coupling basis	189.9	63.3	63.3	21.1	338

[a] Data from Vilmorin (1913).
[b] "Mummy" has glaucous foliage and free seeds, while "Chenille" has emerald foliage and adhering mature seeds.
[c] Ratio of noncrossover to crossover gametes approximates 8:1.

TABLE 25.—*Inheritance of factors A and (Lf)*[a]

Reference to cross.[b]	F_2, F_3, and F_4 classes and frequencies.				Total.
	WE.	RpE.	WL.	RpL.	
P. 277[c]	157	101	35	522	815
Calculated on 7:1 basis[d]	165.9	137.4	36.3	469.2	815
Ratio	4.6	3.8	1	12.9	.....
Calculated on no coupling	51	153	153	459	815
Ratio	1	3	3	9	.....
P. 281[c]	67	16	16	255	354
P. 281[c]	59	21	26	197	303
P. 283[c]	387	104	121	1,361	1,973
Grand total	513	141	163	1,813	2,630
Calculated on 7:1 basis[d]	505	154	154	1,823	2,636

[a] Early White-Flowered Dwarf "(I. P.)" ×Late French Large-Podded "(G. P.)" and reciprocal.
[b] Data and interpretation from Hoshino (1915).
[c] First part of table represents character and frequency of F_2 population. For character of other populations, see Hoshino (1915).
[d] Ratio noncrossover to crossover gametes approximates 7:1.

TABLE 26.—*Inheritance of factors R and (Tl)* [a]

Reference to cross.	F_2, etc. classes and frequencies.				Total.
	RTl.	RA.	WrTl.	WrA.	
RTl×WrA (Pellew)	1,466	20	15	564	2,065
(P38−1×P35−7)−1	45	1	0	13	59
Grand total	1,511	21	15	577	2,124
Calculated on 63:1	1,568.7	16.3	16.3	512	2,113.3
Calculated expectancy on no-coupling	1,188	396	396	132	2,124
WrTl×RA (Pellew)	502	270	264	0	1,036
Calculated on 63:1	516.2	257.9	257.9	.063	1,036
Calculated expectancy on no-coupling	572.3	194.1	194.1	64.7	1,036

[a] Data from Pellew (1913) and the writer's own cultures. Interpretation from Vilmorin and Bateson (1911).

TABLE 27.—*Inheritance of factors G and O* [a]

Cross.	F_2 classes and frequencies.				Total.
	GCl.	GYl.	YGl.	YYl.	
(P21−15−1×P30−A−2)−1	11	0	0	3	14
(P21−15−1×P30−A−2)−2	18	2?	1?	2	23
(P30−5−1×P38−20−1)−1	25	4?	0?	10	39
(P30−5−4×P38−20−1)−1 (670)	29	0?	3?	11	43
(P30−5−4×P38−20−1)−1 (671)	23	0?	2?	5	30
(P30−5−4×P38−20−1)−2	15	0?	10?	5	30
(P57−2×P30−5−7)−1	4	0	0	3	7
(P57−2×P30−5−7)−2	9	0	0	1	10
Grand total	134	6?	16?	40	196
Calculated on no-coupling	109.8	36.6	36.6	12.2	196
Ratio	9	3	3	1	

[a] The question marks refer to the classifications of cotyledon color, the tendency to fade on more or less exposure making accurate determinations in the present case difficult. The linkage in this case may possibly be absolute, but data from other crosses involving these foliage and cotyledon color characters show undoubted cases of plants with green cotyledons and yellow foliage. Further, the writer has a race which breeds true to these characters.